HYDROGEOMORPHOLOGICAL STUDIES IN MARGINAL AND CENTRAL ALLUVIAL PLAIN WITH SPECIAL REFERENCE TO BAH AREA OF AGRA DISTRICT USING REMOTE SENSING TECHNIQUES

DISSERTATION

SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

Master of Philosophy

IN

GEOLOGY
(Remote Sensing)

BY

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Certificate

This is to certify that the work embodied in this dissertation entitled "*Hydrogeomorphological Studies in Marginal and Central Alluvial Plain with Special Reference to Bah Area of Agra District Using Remote Sensing Techniques*" is the original research work accomplished by Mr. Mohammad Sadiq under my supervision at the Department of Geology, Aligarh Muslim University, Aligarh. The research work presented here has not been submitted before at this or any other university and is an original contribution to the existing knowledge of the field.

I allow Mr. Mohammad Sadiq to submit his dissertation for the award of Master of Philosophy in Geology (Remote Sensing) of the Aligarh Muslim University, Aligarh.

Dated:

(Dr. Liaqat Ali Khan Rao)

Dedicated To...

My Revered Father Late Mohammad Haroon and beloved Sister Late Mrs Nargis Anjum who shone like a meteor in my life before disappearing in darkness.

My Parent, Mr. Ikramuddin and Mrs Usmana Begum for their tenderness, sacrifice, and endless support that made my efforts successful. They gave up their own dream to let this dream of mine come true.

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I sincerely hope that the emotions express in this acknowledgement are not just matter of concern rather these are the feelings which are most sincerely true and heartfelt.

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Sadiq

Mohammad Sadiq

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LIST OF ABBREVIATIONS

AWiFS	-	Advanced Wild Field Sensor
CCD	-	Charged Coupled devices
CGWB	-	Central ground Water Board
CIAT	-	International Center for Tropical Research
DEM	-	Digital Elevation Model
EMR	-	Electromagnetic Radiation
ETM	-	Enhanced Thematic Mapper
ETM+	-	Enhanced Thematic Mapper Plus
FCC	-	False Colour Composite
GBF	-	Great Boundary Fault
GIS	-	Geographical Information System
GLCF	-	Global Land Cover Facility
HRV	-	High Resolution Visible
HRVIR	-	High Resolution Visible Infrared (Instrument)
IMD	-	Indian Meteorological department
IRS	-	Indian Remote Sensing (Satellite)
ISRO	-	Indian Space Research Organization
IUGG	-	International Union of Geodesy and Geophysics
LISS	-	Linear Imaging Self Scanning Sensor
MRI	-	Magnetic Resonance Imaging
MSS	-	Multispectral Scanner
NASA	-	National Aeronautics and Space Administration
PAN	-	Panchromatic
PET	-	Positron Emission Tomography
PSLV	-	Polar Satellite Launch Vehicle
RADAR	-	Radio Detection and Ranging
RBV	-	Return Beam Vidicon
SAR	-	Synthetic Aperture Radar
SOI	-	Survey of India
SPOT	-	Système Pour l'Observation de la Terre

SRTM	-	Shuttle Radar Topographic Mission
TM	-	Thematic Mapper
UTM	-	Universal Transverse Mercator
WiFS	-	Wild Field Sensor

Introduction

CHAPTER - I

INTRODUCTION

1 General Statement

The Agra district has one of the richest cultural histories in India and is the hub of tourism in Uttar Pradesh due to the splendors of forts and palaces constructed in the Mughal era. There are 6 Tahsils and 15 Blocks in the district with 114 Nayay Panchayats, 636 Gram Sabhas and 904 villages. Agra had a population of 1,800,000 as per the 2000 census. The Bah Tahsil is the easternmost part of Agra district and belongs to the both the marginal and central alluvial plain (Ganga Plain) between the Yamuna and Chambal Rivers (Misra and Mishra, 2007) covering an area of about 883.18 Km^2. It is an elongated tract having a length of 67.59 km and an average breadth of 14.00 km. About one half of the area of the Tahsil consists of long stretches of deep ravines of the Yamuna and Chambal Rivers flanked by the central elongated and flat topped high land forming the watershed. The progressive increase in the population, industrialization and improper water resources management has caused higher consumption of groundwater and resulted in the lowering of water table. Therefore present study is an attempt to evaluate groundwater condition in Bah Tahsil of Agra district, through hydrogeomorphological studies using remote sensing and GIS techniques and to establish a relationship between geomorphology and groundwater conditions of the area.

1.1 Location and Accessibility

Agra district is located at the southern fringe of Indo-Gangetic plain on the banks of Yamuna River (Fig.1). It is situated in the extreme southwest corner of the State of Uttar Pradesh and is bounded by Mathura district on the north, Dhaulpur district on the south, Firozabad district on the east and Bharatpur district on the west. The study area is 657.77 Km^2 in parts of Bah on the south of Yamuna and Firozabad on the north of Yamuna River and included in the Survey of India toposheets number 54 J/5 and 54 J/9

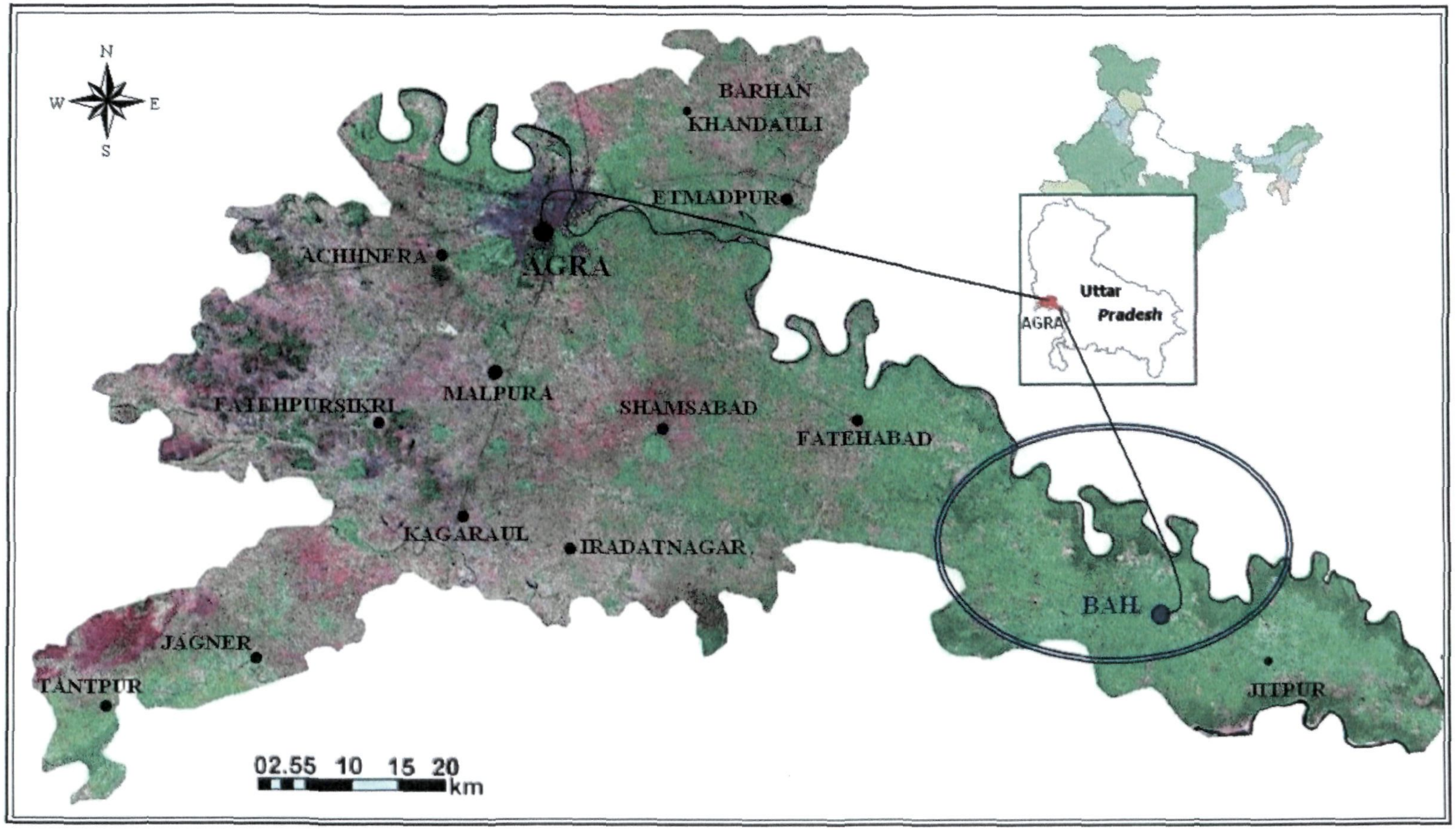

Figure - 1 Location map of the study area

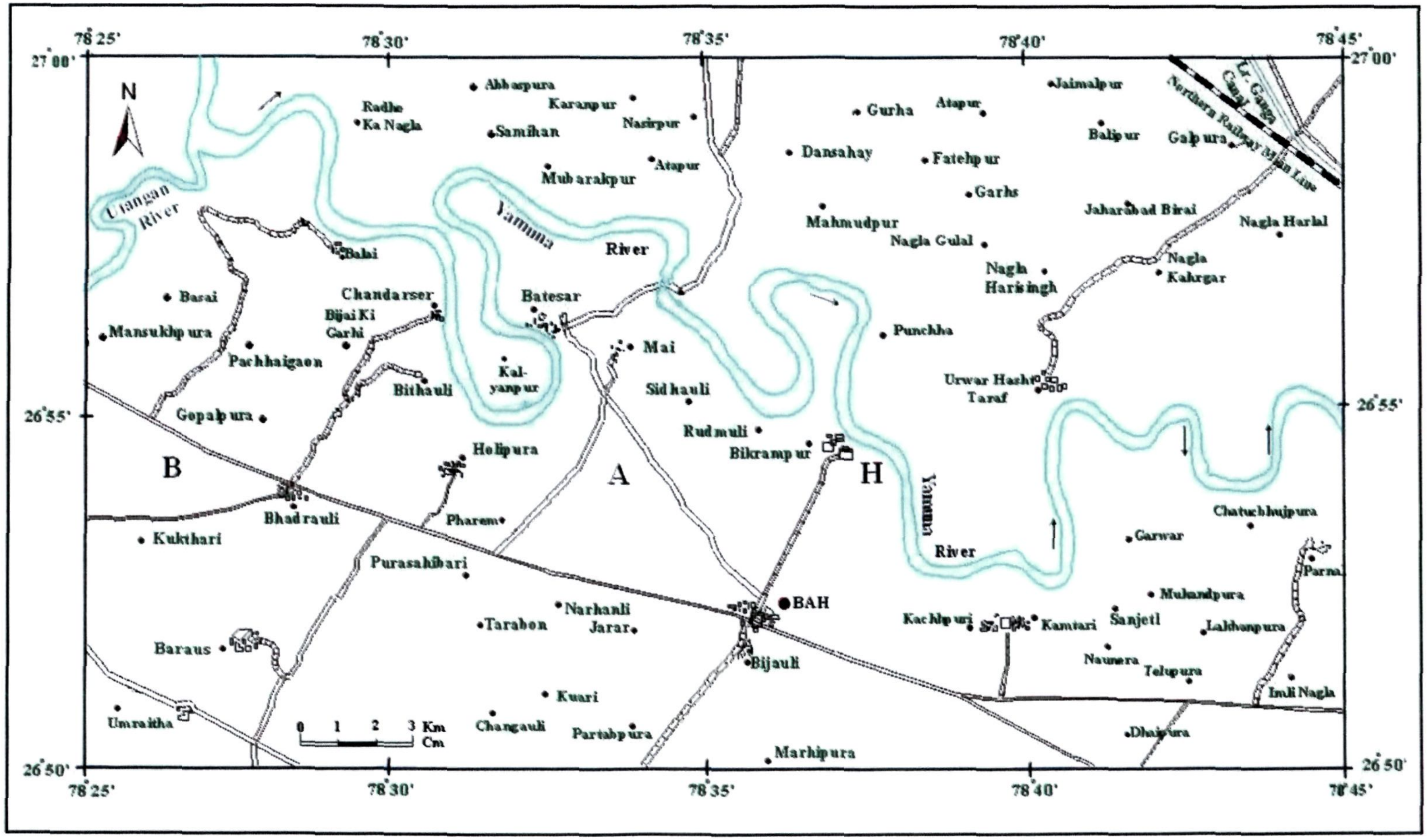

Figure - 1.1 Base map of the study area

between the parallels of 27^0 00' and 26^0 50'N latitudes and 78^0 25' and 78^0 45'E meridians of longitudes (Fig.1.1). Bah Tahsil, southeastern portion of Agra is about 70Km from Agra city and about 55Km from Etawah district. Bah is also famous for Bateshwarnath Temple (Lord Shiva). In the month of November local festival at Bateshwarnath attracts thousands of devotees from nearby areas and states (Rajasthan & Madhya Pradesh).

1.2 Physiography

The world famous historical city, Agra *is situated on the right bank of* the river Yamuna and represented by present flood plain with upland marginal alluviums situating on a monotonous flat surface, sloping from northwest to southeast. The mean sea level of the Agra is 176.8m and the average slope is 1m per 5Km. The most salient feature of relief is the existence of ravines along the Yamuna and Chambal Rivers. To the west of the Chambal, the ravines are still more wild and inhospitable and more bare and barren than those to the east.

The analysis of the digital elevation model obtained from SRTM data shows that the minimum and maximum elevation of the Bah Tahsil is 103m above mean sea level (msl) and 171m above msl where as the mean elevation is 150m above msl, with a relief of 68m. Further analysis of the DEM (Fig.1.2) shows that the minimum elevation is encountered mostly on the southern and northern side of the Tahsil along the Chambal and Yamuna River courses and the neighbouring areas, whereas the maximum elevation is encountered on the western side of the Tahsil.

The general slope of the land surface is from the west to east (Pathak, 1968). To evaluate the variations in the slope and its orientation, the slope and aspect map of Bah Tahsil have been prepared from SRTM-DEM and are shown in Fig.1.3 and 1.4 respectively. The analysis of slope map reveals that slope in the Bah Tahsil varies from 0^o to 12^o. This shows that the area is almost flat with maximum slope ranging from 6^o to 12^o being encountered along the ravines of Yamuna and Chambal Rivers on the northern and eastern side of the Tahsil respectively. The central portion is represented by the gentle

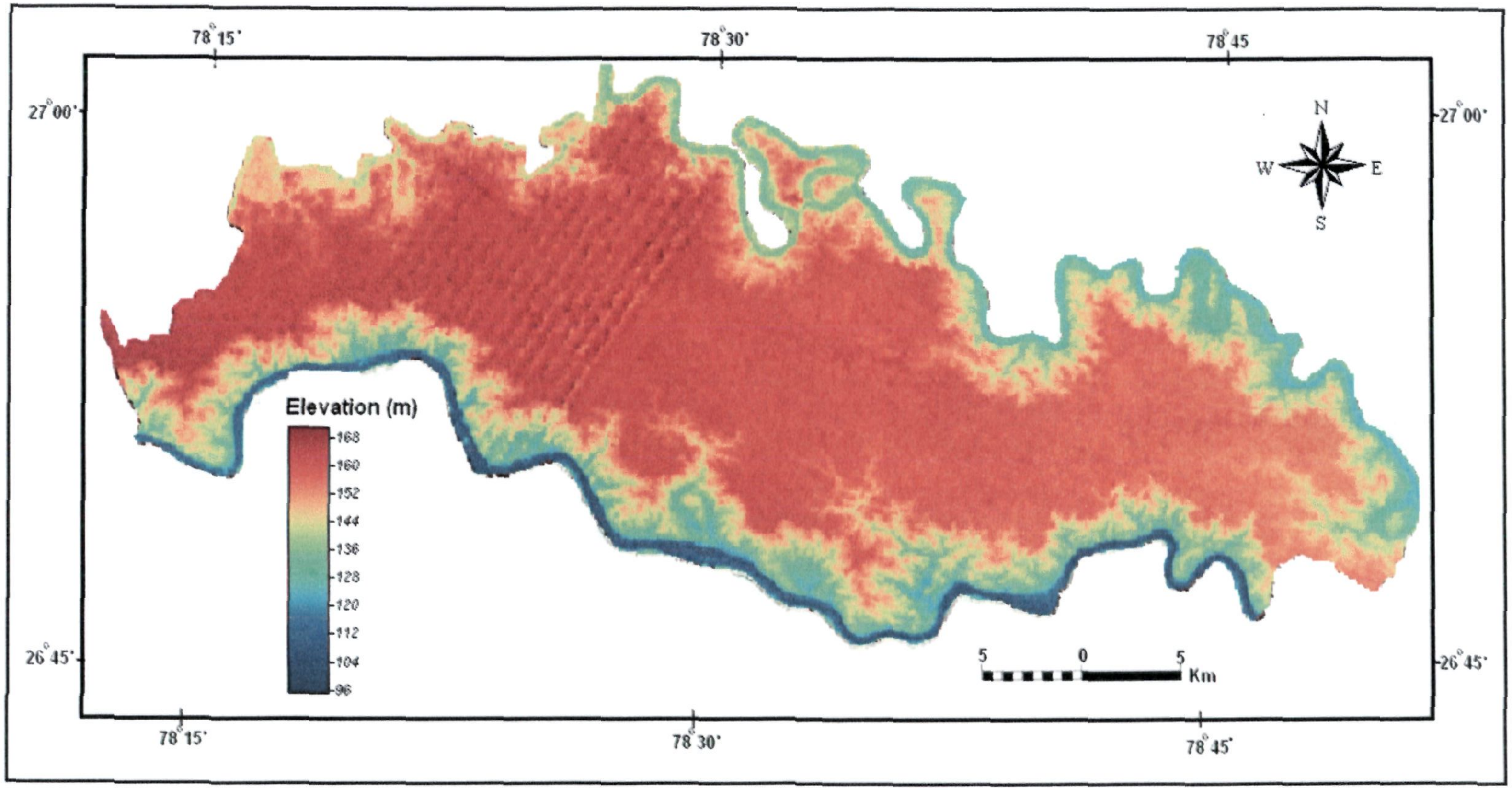

Figure - 1.2 Digital Elevation Model of the Bah Tahsil

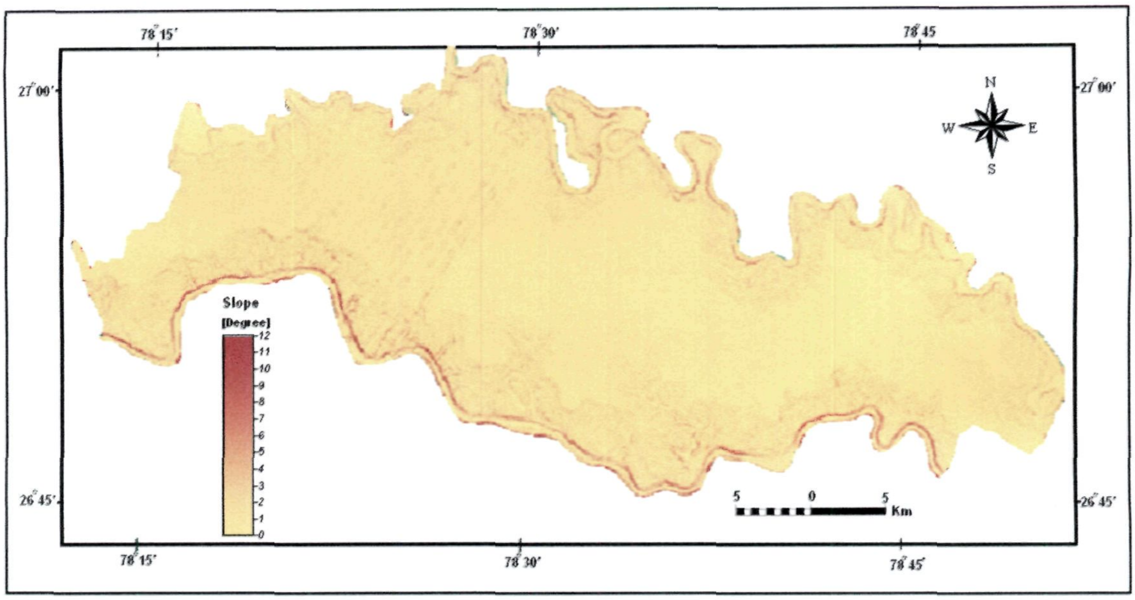

Figure - 1.3 Slope map of Bah Tahsil, Agra

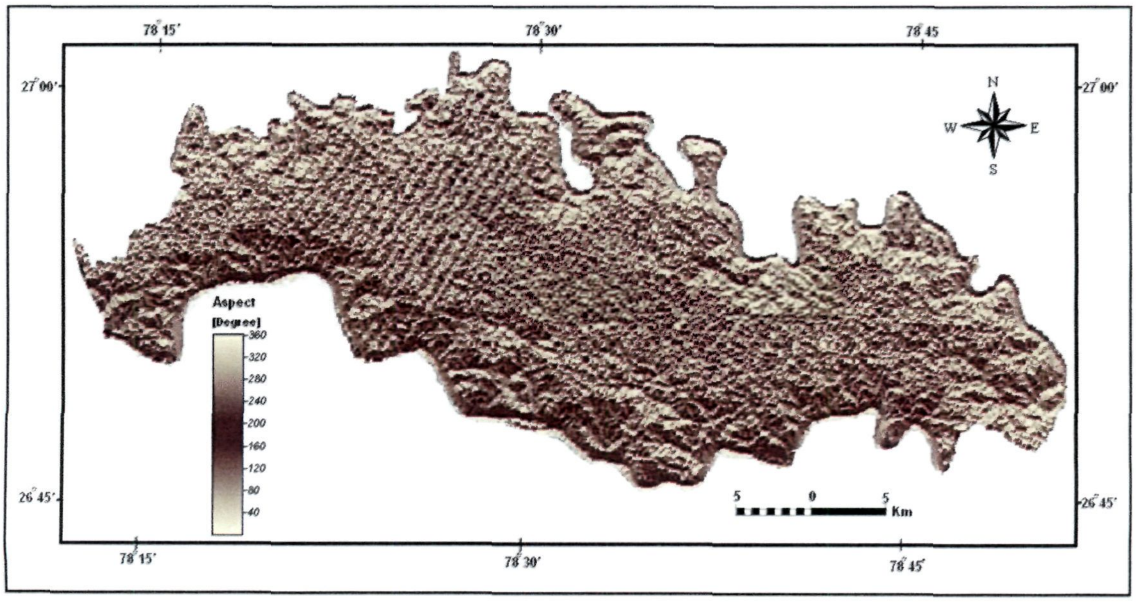

Figure - 1.4 Aspect map of Bah Tahsil, Agra slope ranging from 0^{o} to 5^{o}. The aspect map shows that the mean orientation of the study area is NNW – SSE.

The Agra district is divided in to four parts separated by its important rivers. First comprises Tahsil Etmadpur to the north of Yamuna, the second lies between the Rivers Yamuna and the Utangan covering Agra, Kiraoli, and Fatehabad Tahsils and more than half of the Tahsil Kheragarh. The third lies in the south-east between Yamuna and Chambal comprising the entire area of Tahsil Bah. The last is the remaining tail like portion of Tahsil Kheragarh cutoff by the river Utangan. An off shoot of the Vindhayan hills stretches in to the Tahsils Kiraoli, Kheragarh, and Agra lying in the south-west of Agra. These hills geologically belong to the Upper Vindhyan Supergroup. The Bhandrauli and Fatehpur Sikri spurs are the two parallel, broken ridges of the Vindhyan sandstone running south-west to north -east.

Physiographycally, Agra district is divided into five distinct regions viz. Khadar Lowland, Trans-Yamuna Plain, Yamuna Upland, South-West Upland and Yamuna-Chambal Ravines.

1.2.1 The Khadar Lowland

The Khadar lowland occupies a tract of varying width along the river Yamuna, Chambal and Khari. The soil of Khadar varies from fine sand to silt and mud. The soil, however, is immature. The colour varies from light to ash grey and texture is sandy to silty loam.

1.2.2The Trans -Yamuna Plain

The Trans-Yamuna Plain is a part of the Ganga-Yamuna upland. The general level of the plain is north to southeast. The soil which dominates in the Trans-Yamuna Plain is mainly sandy loam and loamy soil

1.2.3 The Yamuna Upland

The tract lies at a higher level than the Trans-Yamuna Plain; there is no stream in this tract. The uniform stretch of the upland between Yamuna and Utangan includes the Tahsils of Agra viz., Kiraoli, Fatehabad and part of Kheragarh.

1.2.4 South - West Upland

The main feature of landscape is a succession of parallel ridge of red sandstone hills rising about 30 to 60 meters above the plains.

1.2.5 The Yamuna - Chambal Ravines

The Yamuna Chambal Ravines lies between Yamuna and Chambal River in the south eastern part of the area. The area is having a long irregular land, narrow towards the extremities and fairly wide in the centre. Its physical character differs greatly from the others. The level land between Yamuna and Chambal consists of mere ridge and narrow strip flanked on either side by ravines leading to the river.

Physiographically, Bah Tahsil is mainly characterized by the Yamuna-Chambal ravines and Indo-Gangetic alluvium plain.

1.3 Climate and Rainfall

Agra is characterized by semi arid climate. Located on the Indo-Gangetic plain, Agra experiences long, hot summers from April to September where temperature can reach as high as 46° C. During summers dry winds (Loo) blow in this region. The average rainfall in the area is 69 cm (27 in). Agra experiences extreme hot summers and extreme cold winters is not uncommon during the night. Agra is also prone to dense fog during the winter months of December and January.

The India Meteorological department (IMD) has recognized the following climate season in Agra district viz.

A. The season of North Eastern monsoon

a) The cold weather season (Jan-Feb)

b) The hot weather season (March-Mid-June)

B. The season of South West monsoon

a) The season of general rain (Mid-June-Mid-Sep)

b) The season of retreating monsoon (Mid-Sep-Mid-Dec)

1.4 Drainage

The river Yamuna is the biggest and the only perennial river of the region, originates from the Yamunotri glacier of the Himalayas. The origin of river took place in the past Middle-Miocene age. The river enters Agra with a great loop making the boundary with Mathura for little distance. The river shows great meandering in the study area. The drainage follows the general slope and relief feature and follows the direction roughly from NW to SE. The river Yamuna and its tributaries drain the region. Two major rivers, Yamuna and Chambal demarcate the boundary of the district (Fig.1.5).

Whereas there is a low lying area sufficient enough to accumulate rain water and turns immediately into *nalas,* drain one of the larger river or its tributaries. As the process continues these channels gradually becomes more and more pronounced.

There are two perineal rivers on the either side of the Bah viz. Yamuna and Chambal, therefore the land is very fertile, but only the Yamuna River irrigates the majority of land in Agra.

1.5 Vegetation

Primarily the economy of the Agra district is agriculture and tourism based while the economic base of Agra city is small scale industries, commerce and trade. Major crops are wheat, paddy, bajra, mustard, potato, sugarcane etc. Sugarcane and cotton are the main cash crop of the district. Beside these crops, the other plants scattered in and around Agra district include babul, ber, neem and peepal.

In Bah Tahsil low land terraces confined to the Chambal and Yamuna River banks, form the best agriculture tracts. Mustard, wheat, pulses are the main crops grown here.

1.6 Soil

The existing information about the soils of the district is based upon the colour, texture, availability of water supply and the level of the land. Broadly speaking, the soil of this region is alluvial and is categorized into two types viz., the Khandar and Bhanger, which are further subdivided into five types namely: sandy soil, sandy loams (Philiya), loamy soil (Dumat), clayey loam (Matiyar), and clayey soil (Chiknat).

1.6.1 Sandy Soil

The sandy soil occurs over a narrow belt of recent alluvium along river bands of Yamuna Utangan, Khari and the Chambal Rivers. The tract receives generally silty and sandy deposits as a result of the flooding of the rivers. The colour of the soil varies from light to ash gray to ash and the texture is sandy-silty loam. The groundwater table is usually very near to the surface. Agriculture is precarious in the Khadar soils.

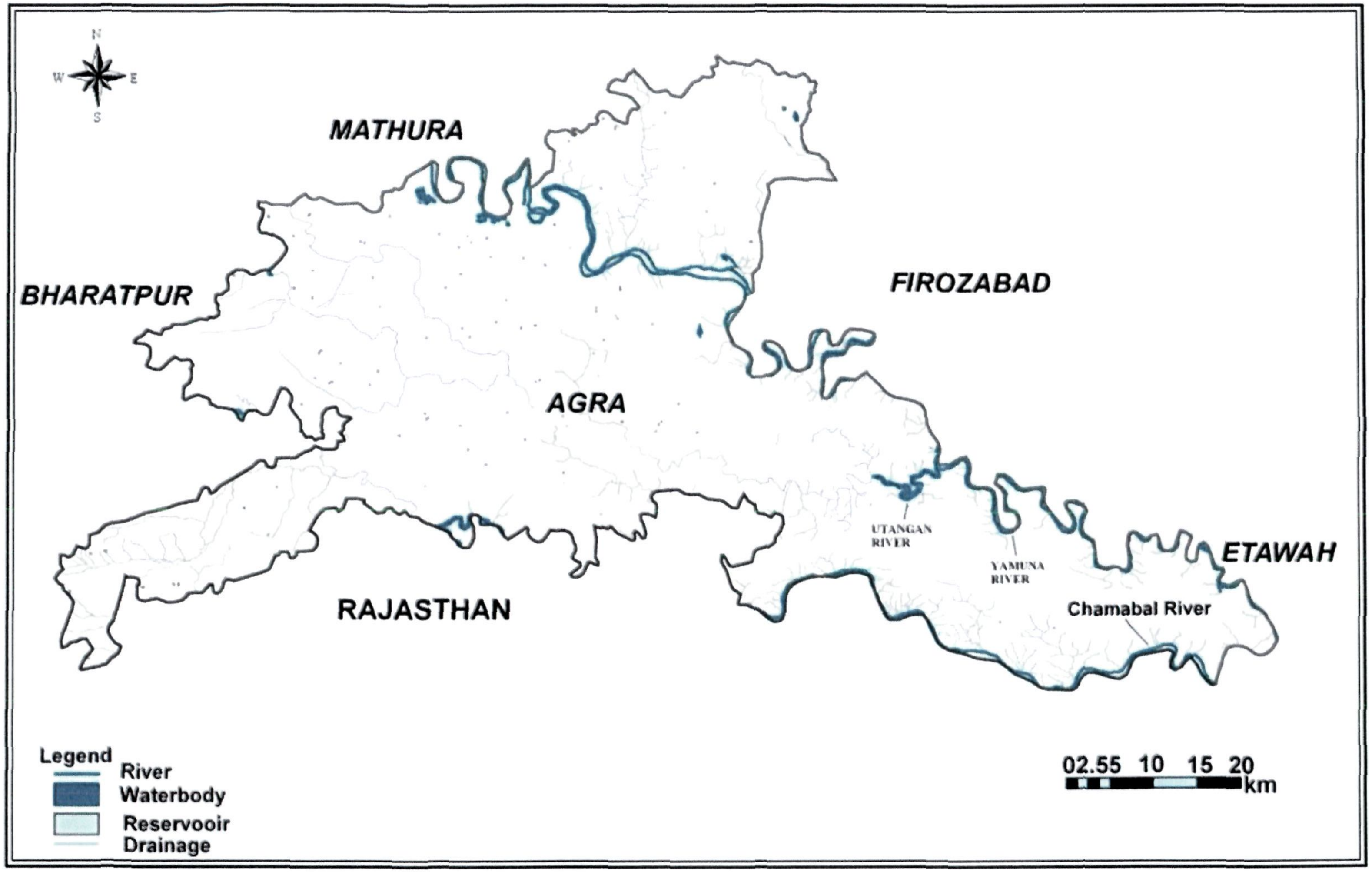

Figure - 1.5 Drainage map of Agra district, Uttar Pradesh

1.6.2 Sandy Loams (Philiya)

The sandy loam occurs in small areas of the Tahsil Kiraoli and Etmadpur. The soil is generally light loam having a large proportion of sand (about 60% coarse and fine sand) in its composition. It is composed of recent alluvium and is generally found near the border of the Khadar lands in a narrow strip. Sandy loam is generally yellow to yellowish brown in the upper horizon and the soil being porous, but it is easy for ploughing and spading. The percentage of organic matter constituents is low, especially in the lower horizon. The sandy nature coupled with low organic content discourages the growth of vegetation.

1.6.3 Loamy Soil (Dumat)

The loamy soil is mainly found in well drained part of the district. It is more productive than sandy loam due to high percentage of fine sand and silt, which together constitutes about 60% of the rock material. The drainage is almost good except where *"kankar"* nodules have accumulated at a depth of 1 to 1.5 meters, which check the water to move freely. The texture of the soil is silty and colour varies from yellowish to brown depending upon the iron oxide and humus. The upper horizon of the soil consists of lesser amount of sand which increases with depth. Consequently, the soil has high moisture retaining capacity in its upper horizon but there is a scarcity in the lower horizon.

1.6.4 Clayey Loam (Matiyar)

The clayey loam locally known as Matiyar, confined to the southwest part of the region (Kiraoli and Kheragarh). At the surface, the colour of the soil is grey to yellowish gray but in the lower horizons they deepen to dark grey colour. The water retention capacity of clayey loam is higher than that of the loamy soils. Moreover, they are rich in clay and at the depth from 0.6 to 1.5 meters calcareous pans *(kankar)* may also occur in the clayey loam. Calcium from the surface is leached is held up and becomes stagnant in the rainy season.

1.6.5 Clayey Soil (Chiknat)

The clayey soil is compact and cloudy and grey to black in colour. The soil become sticky when wet and become very hard when dry and occur in patches in the Tahsil of Bah, mainly in the low lying area of the region. The black clay known as 'Mar' is similar to that of Bundelkhand clay found in Bah. Such type of soil is generally characterized by the salt efflorescence at the surface. In some parts there is large amount of kankar in the subsoil, which often crop out on the surface, rendering the soil unsuitable for agricultural purposes.

The distribution of soil in the study area is uneven (Fig.1.6). In the central part, it is fine loam; in the northern part sandy and in the southern part clayey. The soil along the low terraces of the Yamuna and the Chambal generally known as Kachhars consist of sandy soil and as such crop needs much irrigation.

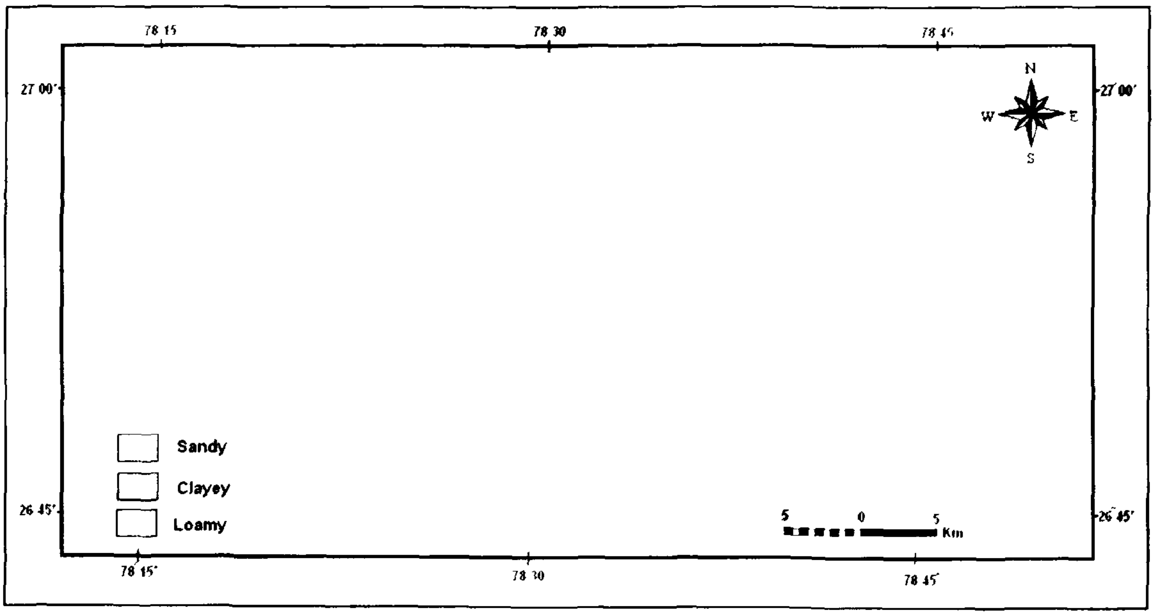

Figure - 1.6 Soil map of Bah Tahsil, Agra

1.7 Aim and Objectives

Most of districts of western Uttar Pradesh are facing problems of groundwater salinity and water scarcity. The problem is compounded by the deteriorating quality of water due to pollution from industrial, agricultural and municipal sources and over-exploitation of its limited reserves.

Agra district of Uttar Pradesh, located along southern fringe of the Indo-Gangetic plain faces scarcity of ground water. Many villages in the district facing even sever scarcity of drinking water either due to poor yield of wells and/or salinity of available resources. In the alluvial covered areas of eastern part, the scarcity is primarily due to poor quality of ground water mainly due to salinity. In study area under the semiarid to arid climatic conditions, the absence of natural flushing by freshwater makes groundwater prone to enhanced salinization, the south western part is covered with hard *compact sandstones where the scarcity is mainly due to absence of weathered/fractured* sandstones. The available surface water resources are inadequate to meet entire water requirement for different purposes and those available are also contaminated with different pollutants. The demand for ground water has increases every year.

Since no comprehensive and scientific investigations have been carried out in the region so far, as part of a complete hydrological appraisal of the watershed, informations on baseline hydrological characteristics and also on spatio-temporal aspects of water resources are not available. In the agricultural sector, the consumption of water is also very high. Since the agricultural sector is increasing by leaps and bounds, the demand for irrigation water is increasing, but due to the saline nature of groundwater in some parts, it cannot be used for irrigation purposes. The large-scale deforestation, mainly due to urbanization, fuel and fodder needs, over exploitation of groundwater, improper water resources management and unscientific management of agriculture practices particularly in Bah Tahsil having some of the major human transformation processes that have been causing reduction in groundwater recharge through increased overland flow and declining rate of infiltration resulting in the lowering of water table upto a considerable depth.

In order to meet the demand of water for economic and agricultural development of the study area an urgent need is felt to explore the new aquifer. The assessment of groundwater resources are primarily base on the comprehensive study of lithology, structure, drainage, landform, hydrogeology etc. are of are of great importance in understanding the hydrogeological behaviour of rocks and soils are also determined and discussed.

Therefore present investigation is an aim to evaluate the groundwater prospect of the study area through the integrated landuse/landcover, morphometric, hydrogeological, geomorphological and hydrogeomorphological studies in parts Bah Tahsil of Agra district using remote sensing and GIS techniques.

1.8 Previous Works

The area has been geologically mapped by Mallet, 1869; Hacket, 1870 and Heron, 1922. Groundwater conditions of the study area have been studied in past by Dutt, 1958 and Pathak and Karanth, 1959. Groundwater investigations of Fatehpur Sikri are done by Choudhary, Agarwal and Sharma, 1988.

Hydrogeological studies in parts of Agra were carried out by Sinha, 1969 whereas hydromorphological units of Agra district were mapped by Seelan, 1988. Hydrogeomorphological and Lineament studies for groundwater prospects are carried out by Rao *et al.,* 2009 and 2010. Impact of urbanization on groundwater in Agra was carried out by Mukherjee and Rai, 1997. Studies on heavy metal contamination of groundwater in Agra were carried out by Gopal, Dayal and Singh, 1989. Wasteland mapping was also done by Rao *et al.,* 2003, but no serious attempt has so far been made in order to identify and delineate groundwater potential zone in the study area.

Studies on geology and groundwater conditions in Bah Tahsil, with reference to soil erosion were carried out by Pathak, 1968 and studies on the escalation of salinity levels in the Quaternary aquifers of the Ganga plain with reference to Bah Tahsil were carried out by Misra and Mishra, 2007.

Database & Methodology

CHAPTER - II

DATABASE AND METHODOLOGY

2 General Statement

The advent of remote sensing has opened up new vistas in prospecting .evaluation, exploration and management of groundwater resources.

Groundwater is a valuable resource in present day but of the limited extent. In order to ensure judicious use of groundwater, its proper evaluation is required. The chemical composition of water is an important factor to be considered before it is used for domestic, irrigation and industrial purposes. However, the quality and quantity of groundwater is controlled mainly by the interaction of topographical, geological, meteorological and pedological features. Moreover groundwater distribution is not uniform and is subjected to wide spatio-temporal variations, depending on the underlying rock formation, their structural fabric, geometry, surface expression etc. Therefore, a detailed hydrogeomorphological mapping and groundwater quality survey can give a clear picture of the groundwater resources and the associated problems.

Satellite remote sensing provides an opportunity for better observation and more systematic analysis of various hydrogeomorphic units, landforms and lineament features following the synoptic, multispectral repetitive coverage of the terrain (Horton, 1945; Suresh *et al.,* 1991; Kumar and Srivastava, 1991; Sharma and Jugran, 1992; Chatterjee and Bhattacharya, 1995; Thomas *et al.,* 1995; Tiwari and Rai, 1996; Ravindran; 1997).

Satellite remote sensing techniques have emerged as a powerful tool in morphometric analysis. Satellite remote has the ability of obtaining synoptic view of large area at one time and very useful in determining the quantitative description of basin geometry i.e. morphometric analysis. The image interpretation techniques are less time consuming than the ground surveys, which if coupled with limited field checks yield valuable results.

The present study is an integrated approach, including morphometry, hydrogeology, landuse/landcover, hydrogeomorphology etc have been taken up, using remote sensing and GIS techniques, for detecting the most suitable zones for groundwater occurrence in Bah Tahsil of Agra district, Uttar Pradesh.

2.1 Data Requirement

The present study was conducted using satellite imageries, survey of India toposheets and other collateral data obtained from the various concern organizations and through ground truths. These data were analyzed further the area of interest has been mapped using remote sensing and GIS.

2.1.1 Data Acquisition

Data used for the present study includes various space-borne data product along with other ancillary data. The following systematic approach involving several steps of acquiring the required data from the concerned sources, its processing and interpretation, generation of thematic maps using satellite data, field visits etc, was adapted to carry out the present study.

1. The available published and unpublished literature, technical reports, special volumes and research papers published in the Journal of the Indian Society of Remote Sensing, relevant to the present study and study area were collected and studied thoroughly.

2. The SRTM-DEM data on 90m spatial resolution of Agra region was downloaded from website http://srtm.csi.cgiar.org/ and used to generate the different terrain components like elevation, slope and aspect.

3. The ortho-rectified Landsat ETM+ satellite data of the study area, available in public domain under NASA sponsored Global Land Cover Facility (GLCF), at University of Maryland website http://glcf.umiacs.umd.edu/index.shtml, was downloaded and further processed for mapping the area.

2.1.2 Data Used

A list of data required and used for analysis is given below:

1. Survey of India (SOI) topographical maps on 1:50,000 scale no.54 J/5 and 54 J/9.

2. FCC of band 234 in (RGB) prepared from Landsat ETM+ data Path 145 Row 42 acquired on 30th Sep, 2001.

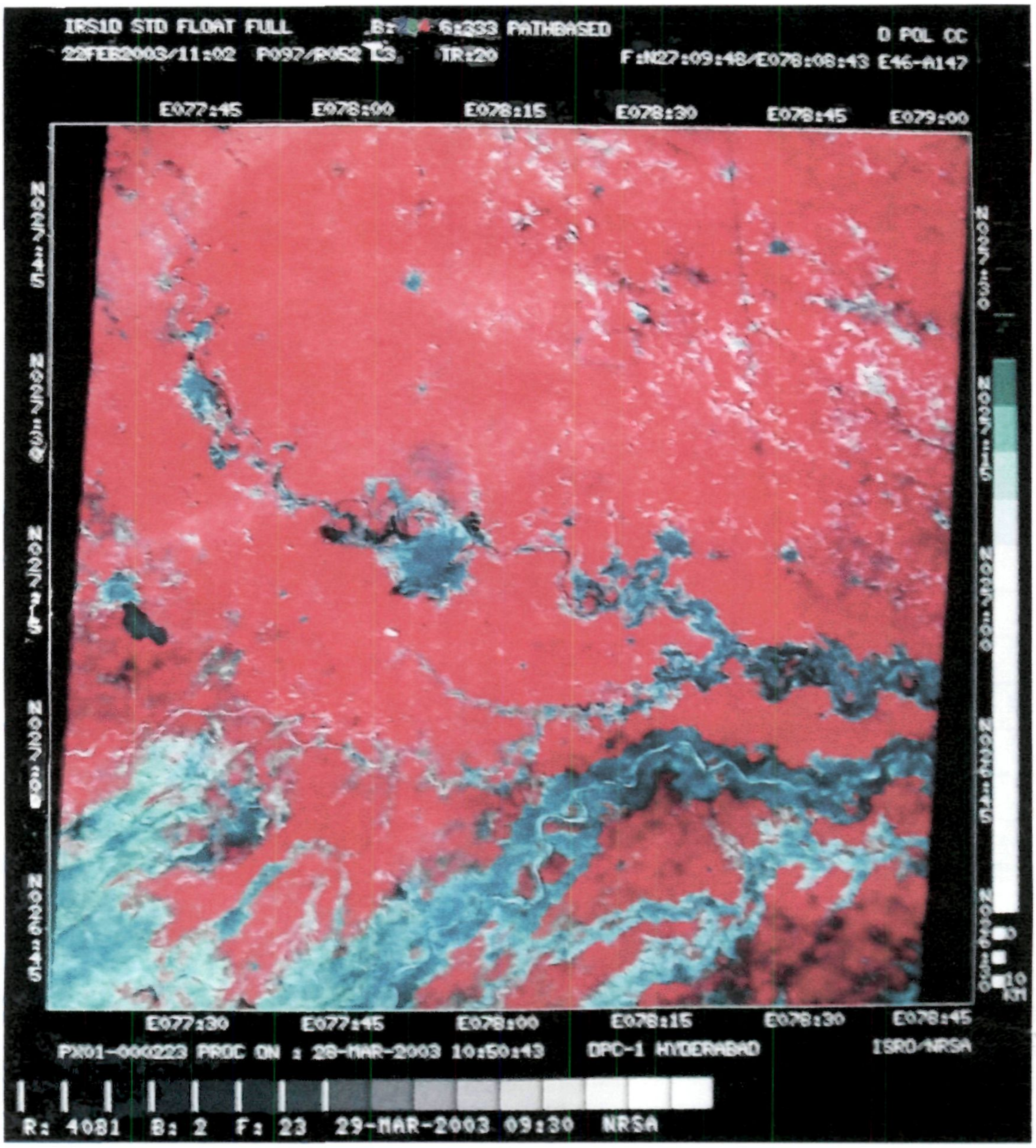

Figure - 2 IRS-ID LISS III Imagery covering the study area

3. IRS-1D LISS-III data (acquired on date 22nd Feb, 2003) of the study area (Fig.2).
4. SRTM 90m resolution data.
5. High resolution satellite imagery available on *Google earth* and *Bhuvan* web pages.
6. Bore hole data collected from U.P. Jal Nigam.
7. Available meteorological data / water level data.

2.1.3 Softwares Used

1. Microsoft Excel module from MS – Office 2003 and 2007 software program, used for making various calculations and plotting of graphs.
2. The different GIS softwares have utilized for the study are, ArcGIS 9.2, Arc-View 3.2.
3. Processing of SRTM data has done using 3DEM and SAGA 2.0.
4. ArcGIS 9.2, Georeferencing Tool 1.0.0.0 and Geographic Translator 2.3 have been used for georeferencing various maps.
5. Multispec W32 used for super00vised classification of the imagery of study area.
6. Map Maker 3 is also used for digitizing work.
7. IrfanView 4.25 has been used to change the image file format and required editing.

2.2 METHODOLOGY

The stepwise methods for preparation of various maps are presented through the flow chart as shown in Fig.2.1 and are described below:

1. Base map was prepared using survey of India topographical maps and satellite imagery of the study area, which show different types of basic information such as roads, canals, railway lines, significant villages, rivers, geographical coordinates and political boundaries.
2. Drainage map of the study area has been prepared initially from SOI toposheets and later updated by IRS-1D, LISS-III analog data. Updated drainage map was used for morphometric analysis of four sub-basins which have been carried out using GIS softwares – ArcGIS 9.2 and ArcView 3.2.

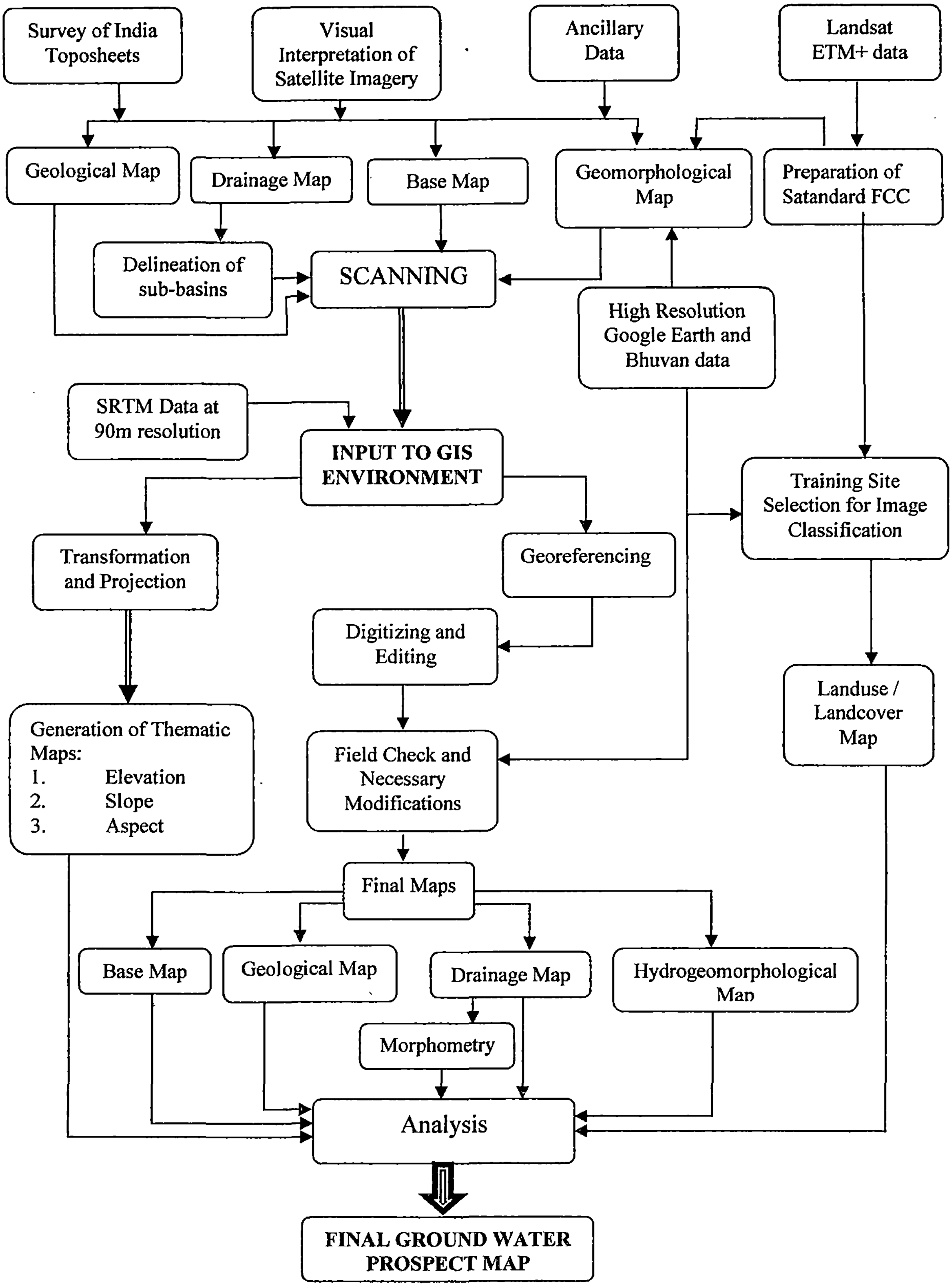

Figure - 2.1 Methodological framework

3. Standard FCCs prepared from the Landsat ETM+ data and IRS-1D, LISS-III were used for landuse/ landcover classification purpose and gomorphological mapping. These maps were further modified by field check and high resolution data available on *Google earth* and *Bhuvan* webpages.

4. Digital Elevation Models which are now becoming increasingly important as tools in hydrological research and water resource management. Therefore SRTM data has been used to prepare different thematic maps viz., elevation, slope and aspect.

5. Final Hydrogeomorphological map has been prepared adopting the following criteria for identification and grouping of landforms i.e.

a. Overall appearance (morphography)
b. The shape/surface geometry (morphometry)
c. The underlying geology
d. Relief forming process
e. Association of landforms.
f. Landuse/landcover analysis

The boundary delineation of landform units has been done on the basis of changes in topographic slopes, relief patterns, crest types and surface texture of landscape under study. The ground verification of interpreted data, along with the high resolution satellite data available on Google Earth, Bhuvan and Wikimapia were carried out for delineating various hydrogeomorphological units, their boundaries and actual geographical position.

6. Geological cross section showing the correlation of aquifers under the area of investigation has also been prepared and an effort was made to achieve the regional picture about the ground water occurrence, movement and its formation.

7. By integrating and analysing the information about various terrain features like elevation, slope, aspect, drainage, geology, geomorphology which exert primary control on occurrence and movement of surface and subsurface water, groundwater prospect map of the study area has been prepared.

2.2.1 Characteristics of SRTM-DEM Data

The Shuttle Radar Topographic Mission (SRTM) successfully collected C-Band (5.6 cm) Synthetic Aperture Radar data over 80% of the landmass of the Earth between 60°N and 56°S latitudes during an 11-day Space Shuttle mission in February 2000. This mission has created an unparalleled dataset of global elevations that is freely available for modeling and environmental applications. There are two SRTM products in raster format: The 30 m (1arc sec) spatial resolution and 90 m (3arc sec) data which is available globally (80% of the Earth surface).The 3 arc sec SRTM data is high quality and can be used to replace the DEM from 1:250000 scale topographic maps in many situations, e.g. for the study of mountain geomorphology, ecology, and hydrology (Liu, 2008). The standard deviation error of the SRTM-DEM over Eurasia has been found to be 8.8 meter for the absolute geolocation, 6.2 meter for absolute height and 8.7 meter, and relative height (Rodriguez *et al.,* 2006). The data is in ARC GRID, ARC ASCII and Geotiff format, in decimal degrees with datum WGS84. CIAT (International Center for Tropical Research) has processed this data to provide seamless continuous topography surfaces. Areas with regions of no data in the original SRTM data have been filled using interpolation methods described by Reuter *et al.,* 2007.

2.2.2 SRTM- DEM Study

The SRTM data is available as 5X5 degree tiles in zipped ArcASCII and zipped GeoTIFF formats and as 1X1 degree tiles in zipped ArcASCII format. In our case the 5X5 degree data set in GeoTIFF format was downloaded. The study area falls on the tile (srtm_52_07, Zone 44) which is, in GeoTIFF format was imported in 3DEM software for cropping the unrequited areas. The cropped tile was processed in SAGA 2.0.3 software to derive elevation, slope and aspect map of the study area.

2.2.3 Characteristics of LANDSAT ETM+

The georeferenced Landsat ETM+ image from the GLCF is provided to the user in GeoTIFF format, one of the most widely supported spatial data formats and used by GLCF as a standard format. Each Landsat ETM+ scene is available with image bands as separate files in its native GeoTIFF file format. The georeference formats employed by the GLCF for Landsat ETM+ image include a UTM projection and a WGS84 datum and ellipsoid. In addition to this georeference information, GLCF has orthorectified the Landsat ETM+ data and by taking ground control points from Landsat TM and DEM. The orthorectification process results in remotely sensed image products that possess both the image based information of the original satellite data and the geometric information of a geodetically accurate map (Compton *et al.,* 2004). The Orbit & Acquisition and Radiometric Characteristics of Landsat ETM+ are presented in Table-1.

Satellite	Sensor	Spectral Resolution micromho (µm)	Band	Spatial Resolution (meters)
Landsat 7	**ETM+**	Band 1: 0.450 – 0.515	Blue	30
		Band 2: 0.525 – 0.605	Green	30
		Band 3: 0.630 – 0.690	Red	30
		Band 4: 0.760 – 0.900	Near Infrared	30
		Band 5: 1.550 – 1.750	Mid Infrared	30
		Band 6: 10.40 – 12.5	Thermal infrared	60
		Band 7: 2.080 – 2.35	Mid Infrared	30
		Band 8: 0.52 – 0.92	Panchromatic	15

Table - 1 Orbit, acquisition and radiometric characteristics of Landsat ETM+ (Source: Landsat Technical Guide, 2009).

2.3 Landuse / Landcover Analysis

The landuse/landcover study of the area has been attempted in order to identify and map the various types of landuse/landcover classes in the area by both visual and digital interpretation. For the classification, independent information (spectral reflectance, fieldwork, analysis of maps and experience) is utilized to define training sites (Fig.2.2). These sites are then used to establish the classification category.

In the present study digital classification was performed using standard FCC prepared from Landsat ETM+ data and processed in Multispec W32 (Fig.2.3). The landuse/landcover units of the study area as identified from this analysis with their areal extent and coverage percentage are given in Table-2 and graphically represented in the Fig. 2.4.

Figure - 2.2 Training sites selected for the Supervised Classification of the imagery of study area

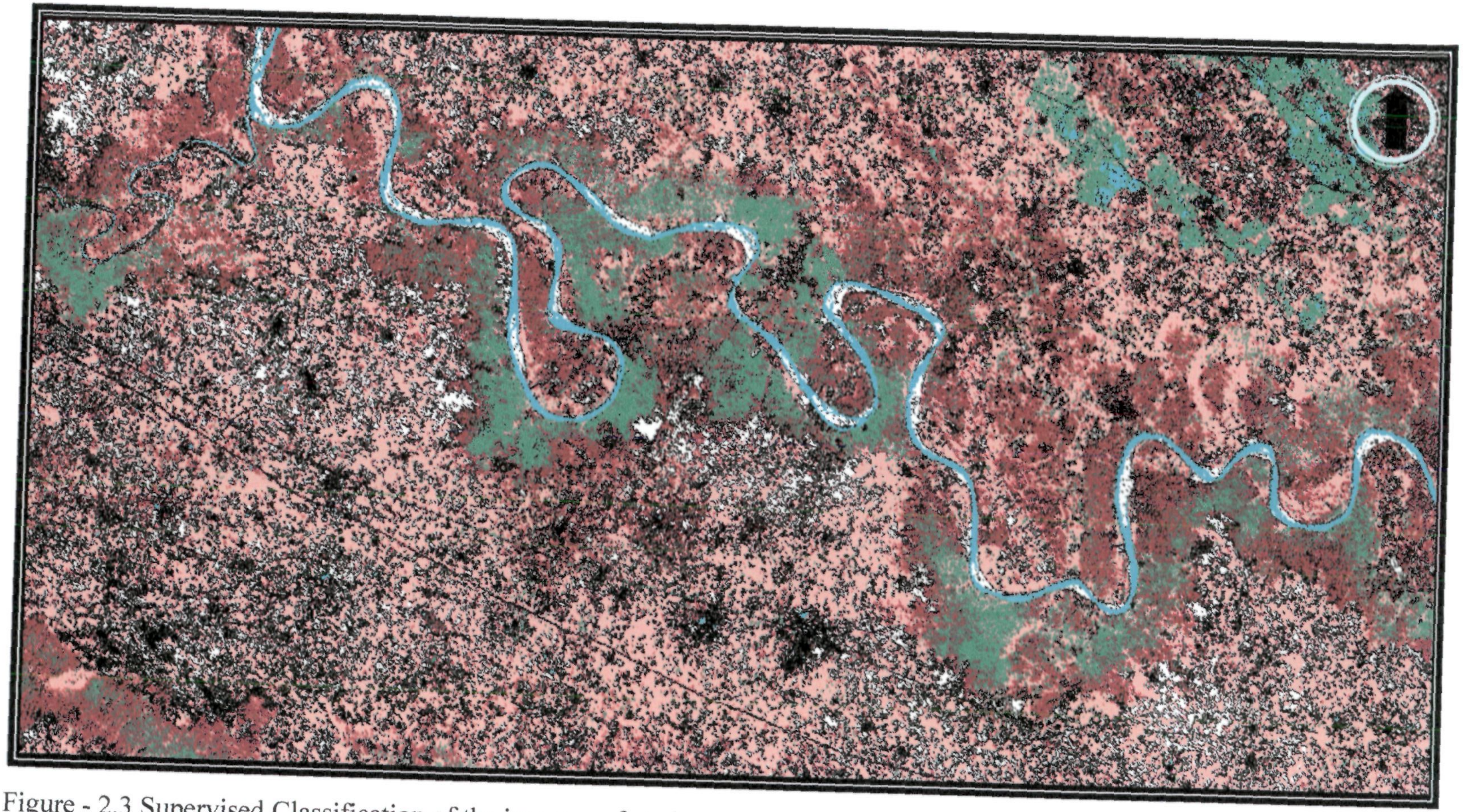

Figure - 2.3 Supervised Classification of the imagery of study area

S.No.	Classes	Area (Sq. Km)	Area (%)
1	River/Water Bodies	16.44	2.5
2	Build Up Area	173.65	26.4
3	Fallow Land	46.70	7.1
4	Agricultural Land	244.03	37.1
5	Ravinous Land	119.71	18.2
6	Forest Cover	57.22	8.7

Table - 2 Landuse/Landcover classes in the study area and their areal extent.

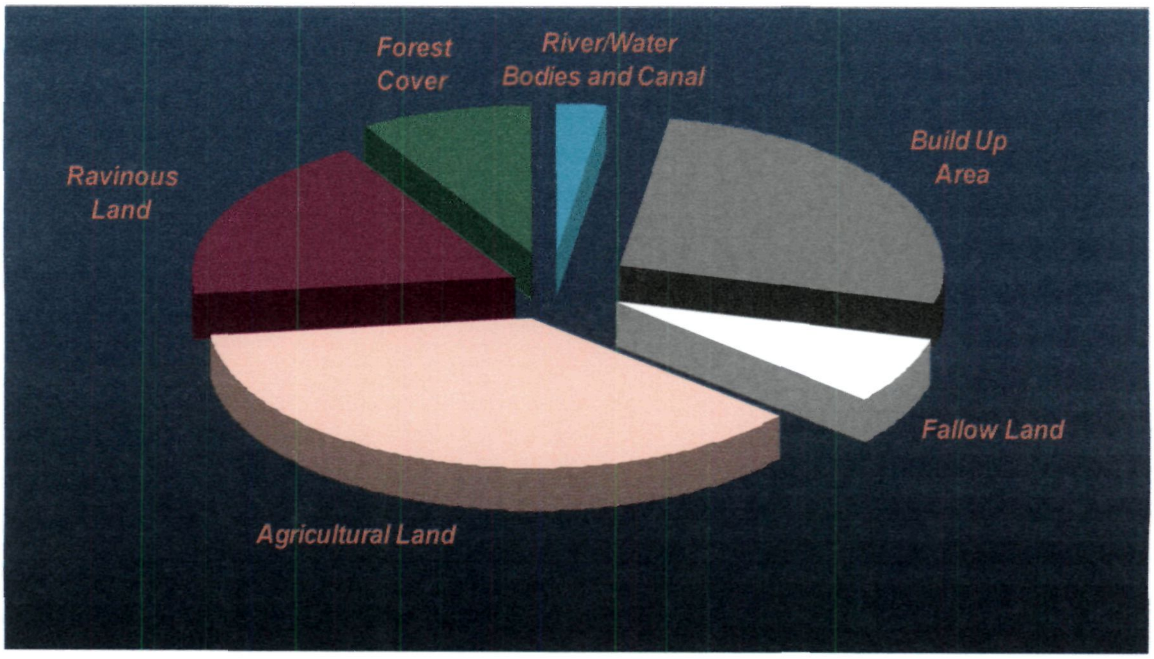

Figure - 2.4 Pie diagram showing the different landuse/landcover classes

Remote Sensing

CHAPTER - III
REMOTE SENSING

3 General Statement

Remote Sensing is the science and art of acquiring information (spectral, spatial and temporal) about material, objects, area, or phenomenon, without coming into physical contact with the objects, or area, or phenomenon under investigation by the use of either recording or real-time sensing device(s) such as by way of aircraft, spacecraft, satellite and ship etc. Remote sensing is the stand-off collection through the use of a variety of devices for gathering information on a given object or area. Thus, earth observation or weather satellite collection platforms, ocean and atmospheric observing weather buoy platforms, Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), and space probes are all examples of remote sensing. Remote sensing makes it possible to collect data on dangerous or inaccessible areas also.

3.1 Major Types of Remote Sensing

The major components of remote sensing system are:

1. In respect to the type of Energy Resources:

   (a) Passive Remote Sensing: Makes use of sensors that detect the reflected or emitted electro-magnetic radiation from natural sources.

   (b) Active remote Sensing: Makes use of sensors that detect reflected responses from objects that are irradiated from artificially-generated energy sources, such as radar.

2. In respect to Wavelength Regions:

   Remote Sensing is classified into three types in respect to the wavelength regions

   (a) Visible and Reflective Infrared Remote Sensing.

   (b) Thermal Infrared Remote Sensing.

   (c) Microwave Remote Sensing.

3. Platforms: Vehicle to carry the sensor (aircraft, space shuttle, satellite, etc.)
4. Sensors: Device to detect electro-magnetic radiation (camera, scanner, etc.)
5. Detectors: Handling signal data (photographic, digital, etc.)

6. Processing: Handling signal data (photographic, digital etc.)
7. Institutionalization: Organization for execution at all stages of remote-sensing technology: international and national organizations, centers, universities, etc.

3.2 Passive and Active Remote Sensing

Remote sensing systems which detect the reflected or emitted electromagnetic radiation from natural sources are called Passive Sensors. The passive sensors can only be used to detect energy when the naturally occurring energy is available and for all reflected energy, this can only take place during the time when the sun is illuminating the Earth, as there is no reflected energy available from the sun at night. Energy that is naturally emitted (such as thermal infrared) can be detected day or night, as long as the amount of energy is large enough to be recorded.

Active sensor, on the other hand, detect reflected responses from objects that are irradiated from artificially-generated energy sources such as radar in order to scan objects and areas where upon a passive sensor then detects and measures the radiation that is reflected or back scattered from the target. RADAR is an example of active remote sensing where the time delay between emission and return is measured, establishing the location, height, speeds and direction of an object.

The advantages of active sensors include the ability to obtain measurements anytime, regardless of the time of day or season. Active sensors can be used for examining wavelengths that are not sufficiently provided by the sun, such as microwaves, or to better control the way a target is illuminated. However, active systems require the generation of a fairly large amount of energy to adequately illuminate targets. Some examples of active sensors are a laser fluoro sensor and synthetic aperture radar (SAR).

3.3 Aerial Photography

Aerial photography is the process of taking of photographs of the ground from an elevated position. The term usually refers to images in which the camera is not supported by a ground-based structure. Cameras may be hand held or mounted and photographs may be taken by a photographer, triggered remotely or triggered automatically. Platforms for aerial photography include fixed-wing aircraft, helicopters, balloons, blimps and dirigibles, rockets, kites, poles and parachutes.

The success of aerial photography, using the visible spectrum of the electromagnetic radiation, suggested that it might be possible to obtain comparable results by using the other wavelength regions. Aerial photography is the form of remote sensing that has played a major role in the discovery of many oil and mineral deposits around the world. Normally, air photos are taken vertically from an aircraft using a highly-accurate camera. There are several things one can look for to determine what makes one photograph different from another of the same area, including type of film, scale, and overlap. Other important concepts used in aerial photography are stereoscopic coverage, fiducial marks, focal length, roll and frame numbers, and flight lines and index maps.

3.4 Satellite Remote Sensing

Satellite remote sensing is defined as the use of satellite-borne sensors to observe, measure, and record the electromagnetic radiation reflected or emitted by the Earth and its environment for subsequent analysis and extraction of information

3.4.1Electromagnetic Spectrum

Sensors collect and store data about the spectral reflectance of natural features and objects, both of which reflect radiation. These radiations can be quantified on an electromagnetic spectrum. The electromagnetic spectrum is a continuum of electromagnetic energy arranged according to its frequency and wavelength. As the electromagnetic waves are radiated through space, their energy interacts with matter in three ways. The radiation will either be:

1. Reflected
2. Absorbed
3. Transmitted

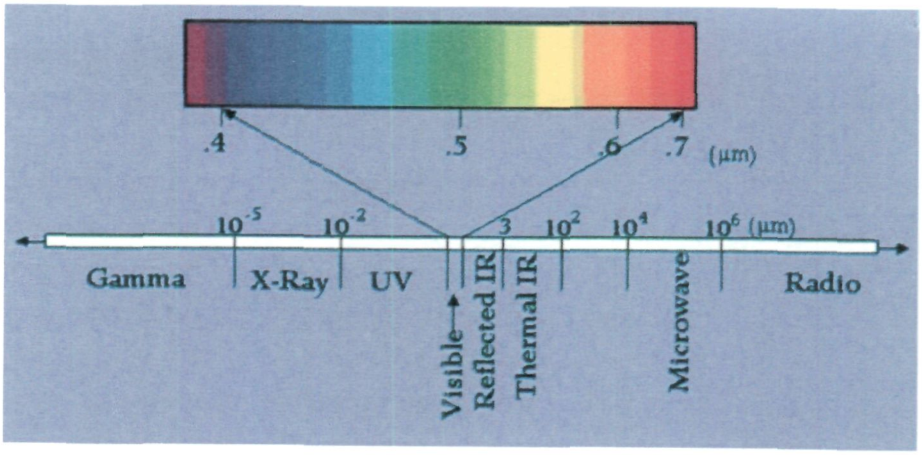

Figure - 3 Different wavelength regions of EMR

The electromagnetic spectrum ranges from the very short wavelengths of the gamma-ray region, measured in nanometers to the long wavelengths of the radio region measured in meters (Fig.3). It may be noticed that the visible region (0.4 to 0.7 μm wavelengths) occupies only a small portion of the spectrum. Energy reflected from the earth during daytime may be recorded as a function of wavelength. The maximum amount of energy is reflected at 0.5 μm wavelength, which corresponds to the green band of the visible region, and is called the reflected energy peak. The earth also radiates energy both day and night, with the maximum energy radiating at 9.7 μm wavelength.

3.4.2 Types of Remote Sensing with Respect to Wavelength Regions

The earth's atmosphere absorbs energy in gamma ray X-ray, and most of the Ultra Violet (UV) region; therefore, these regions are not used for remote sensing. Sensors record energy in the visible & near infrared, reflected infrared, thermal infrared and microwave regions. Remote Sensing is classified into three types in respect to the wavelength regions viz., visible and reflective infrared remote sensing, thermal infrared remote sensing and microwave remote sensing. The various wavelength regions, their characteristics and corresponding remote sensing type are summarized and given in Table-3 (Sabins, 1987).

3.5 Remote Sensing Satellites

3.5.1 LANDSAT

The LANDSAT series of satellites of the USA was the first to provide regular detailed images of most of the earth's surface with about 80m resolution.

The LANDSAT series of satellites are sun-synchronous and have orbits between 705 km and 920 km above the earth's surface.

LANDSAT 1, 2, & 3 have more or less same sensor i.e. MSS (Multispectral Scanner) and a Return Beam Vidicon (RBV). RBV cameras collect the data in three spectral bands, namely green, red and near-infra red.

LANDSAT 4 and LANDSAT 5 equipped with entirely new sensor, the TM (Thematic Mapper) and these satellites provide data in 7 spectral bands (Table-4). The geometric resolution of TM bands is 30x30m except the thermal band in which the minimum detectable element is 120x120m.

Table - 3 Wavelength regions, their characteristics and corresponding remote sensing type.

<table>
<tr><th colspan="5">TABLE -3 ELECTROMAGNETIC SPECTRAL REGIONS</th></tr>
<tr><th>Region</th><th>Wavelength</th><th>Characteristics</th><th colspan="2">Remote Sensing Type</th></tr>
<tr><td>Gamma ray</td><td>< 0.03 nm</td><td>Incoming radiation is completely absorbed by the upper atmosphere.</td><td colspan="2" rowspan="4">Not used in remote Sensing</td></tr>
<tr><td>X-ray</td><td>0.03 to 3.0 nm</td><td>Completely absorbed by atmosphere.</td></tr>
<tr><td>Ultraviolet</td><td>0.03 to 0.4 µm</td><td>Incoming wavelengths less than 0.3 µm are completely absorbed by ozone in the upper atmosphere.</td></tr>
<tr><td>Photographic UV Band</td><td>0.3 to 0.4 µm</td><td>Transmitted through atmosphere. Detectable with film and photodetectors, but atmospheric scattering is sever.</td></tr>
<tr><td>Visible</td><td>0.4 to 0.7 µm</td><td>Imaged with film and photodetectors. Includes reflected energy peak of earth at 0.5 um.</td><td colspan="2" rowspan="2">Visible & Near-Infrared (VNIR) Remote Sensing</td></tr>
<tr><td>Infrared</td><td>0.7 to 100 µm</td><td>Interaction with matter varies with wavelength. Atmospheric transmission windows are separated by absorption bands.</td></tr>
<tr><td>Reflected IR</td><td>0.7 to 3.0 µm</td><td>Reflected solar radiation that contains no band information about thermal properties of materials. The band from 0.7 to 0.9 µm is detectable with film and is called the photographic IR band.</td><td colspan="2">Short-Wave Infrared (SWIR) Remote Sensing</td></tr>
<tr><td>Thermal IR band</td><td>3 to 5 µm, 8 to 14 µm</td><td>Principal atmospheric windows in the thermal region. Images at these wavelengths are acquired by optical-mechanical scanners and special vidicon systems but not by film.</td><td colspan="2">Thermal Infrared (TIR) Remote Sensing</td></tr>
<tr><td>Microwave</td><td>0.1 to 30 cm</td><td>Longer wavelengths can penetrate clouds, fog, and rain. Images may be acquired in the active or passive mode.</td><td>Active or Passive</td><td rowspan="3">Micro-wave Remote Sensing</td></tr>
<tr><td>Radar</td><td>0.1 to 30 cm</td><td>Active form of microwave remote sensing. Radar images are acquired at various wavelength bands.</td><td rowspan="2">Active</td></tr>
<tr><td>Radio</td><td>> 30 cm</td><td>Longest wavelength portion of electromagnetic spectrum. Some classified radars with very long wavelength operate in this region.</td></tr>
</table>

The Landsat programme met with its first unsuccessful mission on Oct 5, 1993, when Lansat-6 was launched. The sensor on board this ill fated satellite was the ETM

Sensor	Mission	Spectral Bands (µm)	Resolution (m)
RBV	1, 2	0.475 – 0.575	80
		0.580 – 0.680	80
		0.690 – 0.830	80
	3	0.505 – 0.750	30
MSS	1 - 5	0.5 – 0.6	79/82*
		0.6 – 0.7	79/82*
		0.7 – 0.8	79/82*
		0.8 – 1.1	79/82*
	3	10.4 – 12.6**	240
TM	4, 5	0.45 – 0.52	30
		0.52 – 0.60	30
		0.63 – 0.69	30
		0.76 – 0.90	30
		1.55 – 1.75	30
		10.4 – 12.50	120
		2.08 – 2.35***	30
ETM	6	Same bands as in TM	30 (120m Thermal Band)
		Plus 0.50 – 0.90	15
ETM+	7	Same bands as in TM	30 (60m Thermal Band)
		Plus 0.50 – 0.90	15

Table - 4 LANDSAT characteristics (Guha, 20008).

* 79m for Landsat-1 to 3 and 82m for Landsat-4 & 5.
**Failed after launch of Landsat-3.
***This band is out of wavelength sequence since it was added to TM later in the original system design process.
Swath width: 185 kilometers
Repeat coverage interval: 16 days (233 orbits)
Altitude: 705 Kms

(Enhanced Thematic Mapper).The latest in the series, Landsat 7, was launched on April 15, 1999. The sensor on board this space craft is the enhanced thematic mapper plus (ETM+).This Sensor system is designed to collect data in 15m resolution data, besides data in seven other bands namely visible, NIR & Middle-IR at a resolution of 30m.

3.5.2 SPOT

A French earth observation satellite, SPOT (Systéme Pour l'Obeservation de la Terre) was launched in Feb, 1986. SPOT image have better resolution than those from Landsat.

SPOT 1 was launched on 22 February 1986, and withdrawn from active service on 31 December 1990. SPOT 2 was launched on 22 January 1990 and is still operational. SPOT 3 was launched on 26 September 1993. An incident occurred on SPOT 3 on November 14, 1996. After 3 years in orbit the satellite has stopped functioning. SPOT 4 was launched on 24 Mar 1998. Engineering work for SPOT 5 has begun so that the satellite can be launched in 2002 to ensure service continuity. To meet the increasing demand for SPOT imagery, notably during the northern hemisphere growing season, SPOT 1 is reactivated in 1997 for routine operation. Currently, three SPOT satellites (SPOT 1, 2, 4) are operational.

Both SPOT-1 and SPOT-2 satellite carries two HRV (High Resolution Visible) sensors. Each HRV system can operate in two modes, namely, panchromatic with 10m resolution and Multispectral with 20m resolution in the visible and the NIR. HRV sensors constructed with multilinear array detectors, operating in a cross-track direction.

The SPOT 4 satellite carries two HRVIR (High Resolution Visible Infrared) detectors. The HRVIR is similar to the HRV, except that HRVIR has an additional short

Mode	Band	Wavelength (μm)	Resolution (m)
Multispectral	XI1	0.50 - 0.59 (Green)	20
Multispectral	XI2	0.61 - 0.68 (Red)	20
Multispectral	XI3	0.79 - 0.89 (Near IR)	20
Multispectral	XI4	1.53 - 1.75 (SWIR)	20
Monospectral	M	0.61 - 0.68 (Red)	10

Table - 5 HRVIR instrument characteristics.

wave infrared (SWIR) band, and the wavelength bandwidth of the panchromatic mode for HRVIR is narrower than that for HRV (Table-5).

3.5.3 IRS (Indian Remote Sensing Satellites)

Remote Sensing technology has evolved in India at a fast pace. The country is undoubtedly the Asian leader in the field of commercial remote sensing. India is presently pressing ahead with an impressive national programme aimed at developing more and more Earth observation satellites to meet the ever-increasing demands, which have been created with the use of this technology.

IRS-1A and IRS-1B

IRS-1A and IRS-1B were launched in Marh 17, 1988 and August 29, 1991 respectively, into a polar, sun-synchronous orbit. The sensor system consist of three push-broom scanners, each based o the Charged Coupled devices (CCD) and each known as the Linear Imaging Self -Scanning Sensor (LISS).

IRS-1C & IRS-1D

India's second-generation operational remote sensing satellites, viz., **IRS-1C** and **IRS-1D**, were launched in Dec, 1995 and Sep, 1997 respectively. The sensors in various satellites of IRS series are presented in Table-6.

The satellite play load consists of:

- A PAN camera having a high resolution of 5.8m.

Sensor	Mission	Band	Wavelength (μm)	Resolution (m)	Swath Width (km)
LISS-I	1A, 1B	Band 1 (VIS)	0.46 to 0.52	72.5	148
		Band 2 (VIS)	0.52 to 0.59	72.5	148
		Band 3 (VIS)	0.62 to 0.68	72.5	148
		Band 4 (NIR)	0.77 to 0.86	72.5	148
LISS-IIA	1A, 1B	Same bands as in LISS-I		74 (146.5*)	74 (146.5*)
PAN	1C, 1D		0.50 – 0.75	5.8	70
		VNIR	0.52-0.59	23.5	142
			0.62-0.68	23.5	142
			0.77-0.86	23.5	142
		SWIR	1.55-1.7	70.5	148
WiFS	1C, 1D	Band 3	0.62 - 0.68	188.3	810
		Band 4	0.77 - 0.86	188 x 188	770
		Band 5	1.55 - 1.69	188 x 246	770

Table - 6 Sensors in IRS series of satellites (Guha, 2008).
* Two LISS II cameras combined swath.

- A Linear Imaging Self-Scanning Sensor i.e. LISS-III operating in four spectral bands, three in the visible and NIR regions and one in the reflected-IR region. It provides a ground resolution of 23.5m except in the reflected-IR band which has a coarse resolution of 70.5 m.

- A two band Wild Field Sensor (WiFS) of a coarser resolution (188.3m) in the visible and NIR regions. Besides, the satellite carries a tape recorder which collects the data even when the satellite is not visible to any ground station.

3.5.4 RESOURCESAT-1

RESOURCESAT-1 is the heaviest earth-observation spacecraft launched by ISRO so far. It was launched into an 817 km sun-synchronous polar orbit on board Polar Satellite Launch Vehicle (PSLV-C5) on October 17, 2003. It is the most advanced satellite built by ISRO, bringing continuity to the current IRS 1C and 1D programme. RESOURCESAT-1 carries three sensors i.e. LISSII, LISS-IV, and AWiFS (Advanced

Sensor	Mission	Band	Wavelength (μm)	Spatial Resolution (m)	Swath Width (km)
LISS-IV	Resourcesat-1	Band 2 (green)	0.52 – 0.59	5.8 m	70
		Band 3 (red)	0.62 – 0.68	5.8 m	70
		Band 4 (NIR)	0.77 – 0.86	5.8 m	70
LISS-III	Resourcesat-1	Band 2 (green)	0.52 – 0.59	23. 5	140
		Band 3 (red)	0.62 – 0.68	23.5	140
		Band 4 (NIR)	0.77 – 0.86	23.5	140
		Band 5 (SWIR)	1.55 – 1.70	23.5	140
AWiFS	Resourcesat-1	Same Bands as in LISS- II		56	700

Table - 7 Sensors in Resourcesat - 1 satellite (Guha, 2008).

Wild Field Sensor) that deliver an array of spectral bands and resolutions ranging from 5.8 m to 56 m. Data products derived from RESOURCESAT-1 can be used for advanced applications in vegetation dynamics, crop yield estimates, disaster management support etc. In addition, RESOURCESAT-1 has 120 Gigabits of on-board memory that allows for out-of-contact imaging. Scheduled to last for five years, RESOURCESAT is the tenth spacecraft of ISRO in the IRS series. The sensors in Resourcesat-1 satellite are given in Table-7.

3.5.5 CARTOSAT-1 & 2

The images from the Cartosat-1 have been useful for generating digital elevation maps, particularly for urban and rural development and for cartographic applications, i.e. generation of large scale maps, updating of topographic maps.

The second mapping satellite, **Cartosat-2** was launched by ISRO in the polar sun-synchronous orbit at an altitude of 635 Km in Jan, 2007 and is the latest in the IRS series of satellites.

Sensor	Mission	Spectral Bands (μm)	Resolution (m)
PAN fore camera	Cartosat-1	0.50-0.85	2.5
PAN aft camera	Cartosat-1	0.50-0.80	2.5

Table - 8 Sensor characteristics of Cartotosat (Guha, 2008).

The sensor in it is a state-of-the-art PAN camera (Table-8) providing black and white pictures in the visible region of the electromagnetic spectrum (0.5-0.85 μm with a ground resolution better than 1 m and a swath of 9.6 km.

3.6 Applications of Remote Sensing in Groundwater Prospecting

Remote sensing and GIS methods permit rapid and cost effective natural resource survey and management. Moreover, remotely sensed data serve as vital tool in groundwater prospecting (Sharma and Jugran, 1992; Chatterjee and Bhattacharya, 1995; Tiwari and Rai, 1996; Ravindran, 1997 and Horton, 1945). The traditional use of remotely sensed image interpretation lies in the qualitative characterization of hydrogeological mapping units and detection of specific features.

Identification and location of groundwater is primarily based on indirect analysis of some directly observed terrain features like geological and geomorphic features and their hydrologic characters. The use of stereo aerial photo-interpretation was described by Goosen, 1967 for soil mapping, by Verstappen, 1977 for geomorphology and by Way, 1978 and Townshend, 1981 for terrain analysis and physiography.

Satellite remote sensing provides an opportunity for better observation and more systematic analysis of various geomorphic units, lineament features, following the integration with the help of Geographical Information System to demarcate the groundwater potential zones. Long wave radar can sometimes detect groundwater levels at depths of a few meters and other subsurface features, such as buried channels (McCauley *et al.,* 1982). Radar imagery has its general use in hydrogeology for the interpretation of geological structures (Koopmans, 1983 and Drury, 1993). The surface features contained in the imagery of the reflected shorter wavelengths relate to the surface expression of geological and geomorphological features and land cover. Hence, indirect hydrogeological informations are obtainable from satellite images.

The visual interpretation of aerial photograph and satellite images with ground truth data provides adequate information about the hydrological behavior of rock occurring in the area. False Color Composites of Thematic Mapper data appear to the most useful for mapping of hydrogeomorphological unit. However, the uses of aerial photograph in groundwater studies gained impetus in the year of 1950. Howe, 1958 have described procedures of air photo-interpretation applied in locating groundwater for mapping Groundwater prospect zones from aerial photographs. In the year of 1972, it has become possible to map the potential zones of groundwater by satellite images with the successful launch of LANDSAT - 1 in 23rd July. Roy (1972, 1976, and 1979) and Sharma *et. al.* (1975) has explained the successful use of hydrogeomorphological approach in groundwater mapping. In hard rock areas the fractures and weathered zones serve as a fruitful exploration base in planning of ground water prospects (Baweja *et al.,* 1979).The application of remote sensing of groundwater exploration has been described by Cho *et. al.,*1989. LANDSAT data were used for groundwater study in the Kalahari plateau of Botswana by Gurney *et. al.,*1982. The principal application corresponding to bands of different sensor deployed in LANDSAT,
SPOT and IRS-1A & 1B are given in Table-9.

The main trends of remote sensing applications for groundwater exploration have explained by Roy (1984) as:

1. Mapping of drainage and drainage network analysis.
2. Mapping of landforms, land use and change therein.
3. Geologic and structural mapping vis-à-vis groundwater control.
4. Mapping of vegetation and drainage anomalies as indicators for Groundwater.
5. Evaluation of soils (hydrologic soil groups) and soil moisture conditions.

Table - 9 Principal applications corresponding to bands of different sensor deployed in LANDSAT, SPOT and IRS-1A & 1B.

Satellite	Sensor	Band	Wavelength	Principal Application
LANDSAT	MSS	4	0.5 - 0.6	Sediment, rock type, lineament, water delineation, shallow water areas.
		5	0.6 – 0.7	Cultural Features, vegetation types, aerial extent of water, cloud cover mapping.
		6	0.7 – 0.8	Vegetation, boundaries between land & water, landforms.
		7	0.8 – 1.1	Penetration of atmospheric haze, vegetation, water bodies, landforms, cloud mapping
		1	0.45 – 0.52 (Blue)	Water body penetration, coastal water mapping, soil and vegetation discrimination, forest mapping, and cultural features identification.
		2	0.52 – 0.60 (Green)	Green reflectance peak of vegetation, cultural feature.
		3	0.63 – 0.69 (Red)	Chlorophyll absorption region aiding in plant species differentiation.
	TM	4	0.76 – 0.90 (NIR)	Vegetation type, biomass contact, delineation water bodies, soil moisture.
		5	1.55 – 1.75 (Reflected IR)	Vegetation moisture and soil moisture.
		6	10.4 – 12.5 (Reflected IR)	Vegetation stress analysis, soil moisture, thermal mapping.
		7	2.08 – 2.35 (Thermal IR)	Mineral and rock type discrimination, hydrothermal mapping.
		Panchromatic Mode	0.52 – 0.73	I. Topographic feature in 15 – 30 m should be visible. II. Drainage between 10 & 20 m should be visible less than 5 m may be detected.
SPOT	HRV	Multispectral Mode		III. Lineament identified from LANDSAT will be easily visible on SPOT.
		1	0.50 – 0.59	IV. Small geological features like gossans, dykes, intrusion and rock inliers in the order of 10 – 80 m in diameter and width will be more easily identified.
		2	0.61 – 0.68	V.Small field pattern can be identified and mapped
		3	0.79 – 0.89	VI. Wide range of land – cover types can be recognized that is grass land, woodland, bare soil, mineral working, quarries. VII. Improved Identification of landcover types due to greater radiometric and spatial resolution by supervised classification procedure.
IRS	LISS	1	0.45 – 0.52	Coastal environmental studies, chlorophyll absorption region.
		2	0.52 - 0.59	Green vegetation, useful for discrimination of rocks and soil for their iron content.
		3	0.62 – 0.68	Strong correlation with chlorophyll absorption in vegetation, discrimination of soil, and geological boundaries.
		4	0.77 – 0.86	Sensitive to green biomass, opaque to water resulting in high contrast with vegetation.

6. Delineation of Groundwater potential zones, based on geologic as well as landscape studies (hydromorphogeology).

The infra-red images are used to map the temperature variation of ground surfaces, enables the evaluation of groundwater resources (Todd, 2003). Shallow aquifers can be delineated by thermal infrared data taken at appropriate times of the diurnal and seasonal temperature cycles (Heliman and Moor, 1980). Thermal data may also be used to identify alluvial deposits. Shallow ground water, spring and through the difference in temperature resulting from near surface Groundwater (Engman and Gurney, 1991).

The Synthetic Aperture Radar (SAR) is very useful in groundwater prospecting, particularly in arid areas. It can detect the soil moisture by virtue of the penetrating capability of long wave.

Singh *et al.,* 1979 have measured the dependence of dielectric constant of soil on the moisture content in the X-band. From the preceding discussion it appears that the knowledge of physiography, soil, land use / land cover, vegetation cover, drainage, depth and intensity of weathering, hydromorphogeological units and lineaments is essential in the resource exploration of ground water.

Rango (1994) reviewed the use of remote sensing in hydrology but did not list groundwater among its operational applications, possibly because "most approaches use surficial indicators of the underlying groundwater reservoir and require considerable skill and knowledge on the part of the interpreter". This is true, but it does not prevent an operational use by many hydrogeologists in certain types of shallow groundwater systems.

Geological Set Up

CHAPTER - IV

GEOLOGICAL SET UP

4. General Statement

The State of Uttar Pradesh practically represent all aspects of the geological phenomena and processes that give rise to present day development of the Indian subcontinent. The central part of the state constitutes vast alluvial plain called the Ganga Basin. It has been described as a fore deep and represents a great depression related to a fracture several thousand feet deep in the earth's sub-crust. This depression is characterized by a basement ridge and three prominent faults.

The study area is a part of Indo-Gangetic alluvium of the Quaternary age and is made up of recent unconsolidated fluviatile formations comprising sand, silt, clay and kankar with occasional beds of gravel. The rock units belonging to the Vindhyan Supergroup represented by the Upper Bhander and Lower Rewa Sandstones are exposed in the west and southwest of Agra. Bah Tahsil comprises mainly of older alluvium of middle to Upper Pleistocene age and forms a part of Indo-Gangetic alluvium.

4.1 Geology of Uttar Pradesh

The State of Uttar Pradesh comprises an area of about 2, 40,928 Km^2 and forms one of the largest states in the country. It extends from latitude $23^0 52'15''$ to $30^0 25'05''$N and longitude $77^0 05'36''$ to $84^0 38'10''$E and is characterised by rock formations ranging in age from the Archean (the Bundelkhand Graniticgneisses) to the Recent (the Ganga alluvium) (Fig.4). The Ganga plain which dominates the landscape and nearly covers three fourth of the geographical area of the state, lies between the rocky Himalayan belt in the north and the southern hilly tract comprising mainly the Pre-Cambrian rocks.

Flexing of the Indian lithosphere in response to the compressive forces due to collision, and thrust fold loading produced the Ganga Plain Foreland basin which is filled with recent alluival sediments, more than 1,000 m. thick at places and an

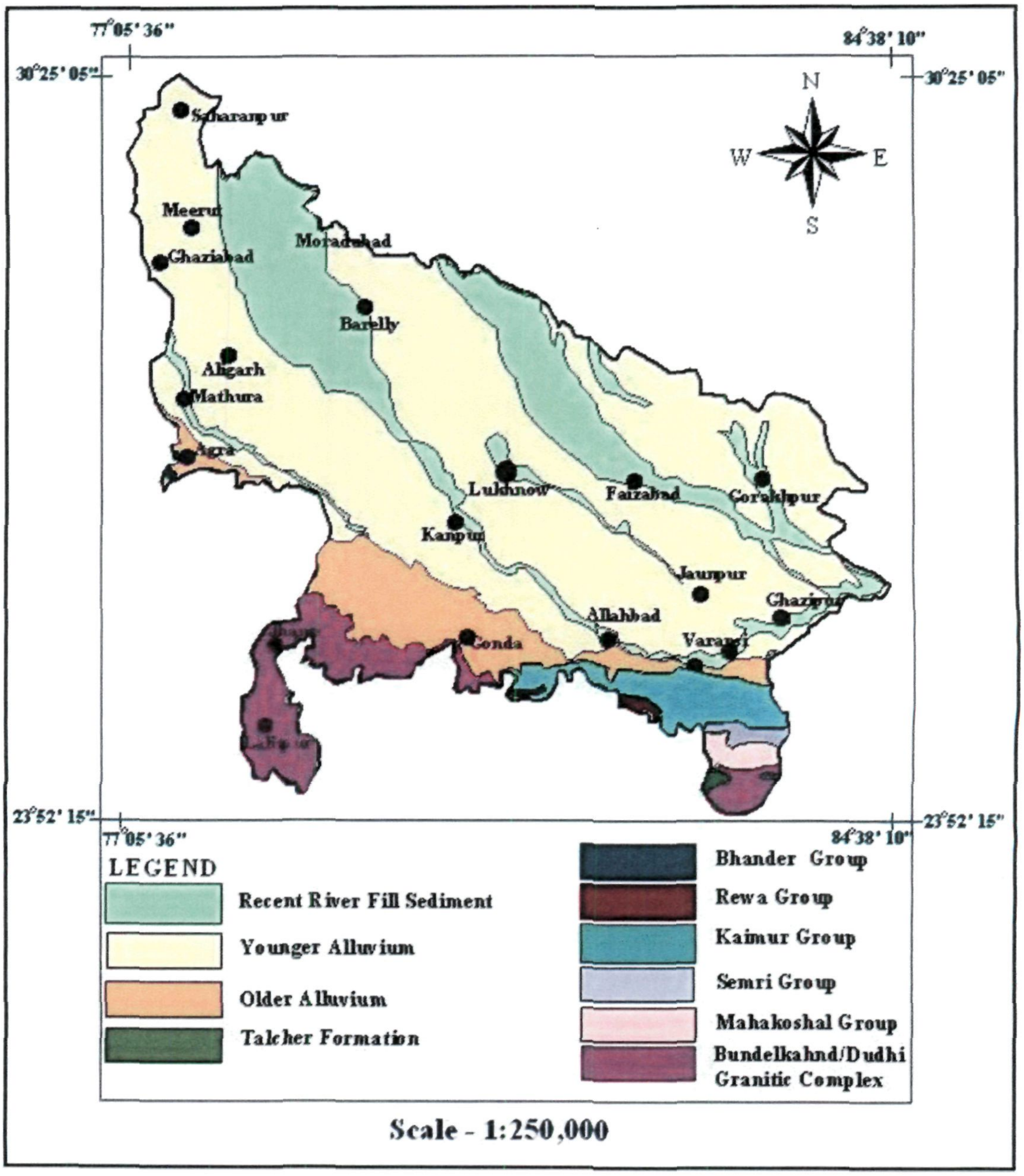

Figure - 4 Geological map of Uttar Pradesh, India complex in Bundelkhand region and in Sonbhadra. It is overlain by rocks belonging to the Mahakoshal (Bijawar) and the Vindhyan Supergroup. The younger rocks comprise of coal bearing Gondwana in south Sonbhadra and basaltic rocks in southern part of Lalitpur. The granitic complex is considered to be potential for the search of metallic minerals like copper, lead, zinc, molybdenum, gold, nickel, uranium and platinum group of elements. The overlying sediments of Mahakoshal (Bijawar) and associated Iron Formation show a potential for the search of copper, uranium, and gold in Lalitpur and andalusite, sillimanite, gold, calcite, marble and clay in Sonbhadra. The Lower Vindhyan sediments of Sonbhadra contain deposits of cement grade limestone, flux grade dolomits, building stone and are also potential for the search of placer gold and other metals. While the Upper Vindhyan sandstones are suitable for making decorative slab/tiles or ballast. Deposits of silica sands and bauxite are available in Allahabad and Chitrakoot districts while coal deposits occur in the Gondwana rocks in southwestern corner of Sonbhadra (http://mineral.up.nic.in/geological_map.htm).

4.2 Geology of Agra

Geologically the area in and around Agra is characterized by the rocks belonging to the Delhi Super Group, the Vindhyan Supergroup and the Quaternary sediments (Fig.4.1). The Delhi Super Group is represented by the Alwar and Ajabgarh Formations characterized by medium grained quartzite of the Alwar Formation predominantly of arenaceous facies exposed in Kankan area near Mathura. The upper part of the succession belonging to the Ajabgarh Formation composed of argillaceous-calcareous slate and schist are well exposed in Goberdhan and west of Bharatpur district, Rajasthan. The Vindhyans in the study area is represented by Upper Bhander and Lower Rewa sandstone. The Quaternary sediments mainly consist of sand, gravel and clay.

The Upper Vindhyan is found in an almost continuous but irregular outcrop from Chittor in the west to Sasaram in the east. A large and roughly square area the "blade" of the "axe" mentioned in 250 miles across its diagonal and having its four corners at Achhnera in the north. Vindhyan sediments are mostly tidal deposit.

The general geological succession in the Agra as given by Heron (1922) and later by Pathak and Karanth (1959) with modification is given in Table-10 below:

Quaternary	Recent to upper Pleistocene	Newer alluvium	Sand and Gravel
		Older alluvium	Sand, silt, clay & Kankar
		Laterite and clay	Laterite and clay
~~Unconformity~~~			
Precambrian	Vindhyan Supergroup (Upper Vindhyan)	Upper Bhander Sandstone	Hard and Compact Sandstone
		Lower Rewa Sand stone	Hard and Comapct Sandstone
~~Unconformity~~~			
		Delhi Supergroup	

Table - 10 General geological succession in Agra.

The rock formations of Vindhyan Supergroup exposed in the study area are identified as Lower Rewa Sandstone and Upper Bhander Sandstone and are discussed below.

a) Lower Rewa Sandstone

The Lower Rewa Sandstone occurs as discontinuous strike ridges southwest of Bayana. The Rewa Sandstone is white to pinkish in colour and comprises mainly of compact, hard, fine grained, bedded sandstone and is generally less ferruginous than the sandstone of overlying Upper Bhander. The sandstone dips 5^0 to 20^0 towards southwest.

b) Upper Bhander Sandstone

The Upper Bhander Sandstone is reddish in colour, hard, compact and fine-grained and characterized by white to fine grained spots. The presence of ripple marks and current bedding in these sand stone indicate deposition under shallow water condition.

c) Quaternary Sediments

The Quaternary sediments include sand and gravel beds in the form of alluvium and serves as good aquifer. The size of the sand varies from fine to coarse with sub angular to rounded grain. The sand is moderate to highly permeable. The major part of the area is covered by Gangetic alluvial deposit of the Quaternary age comprising

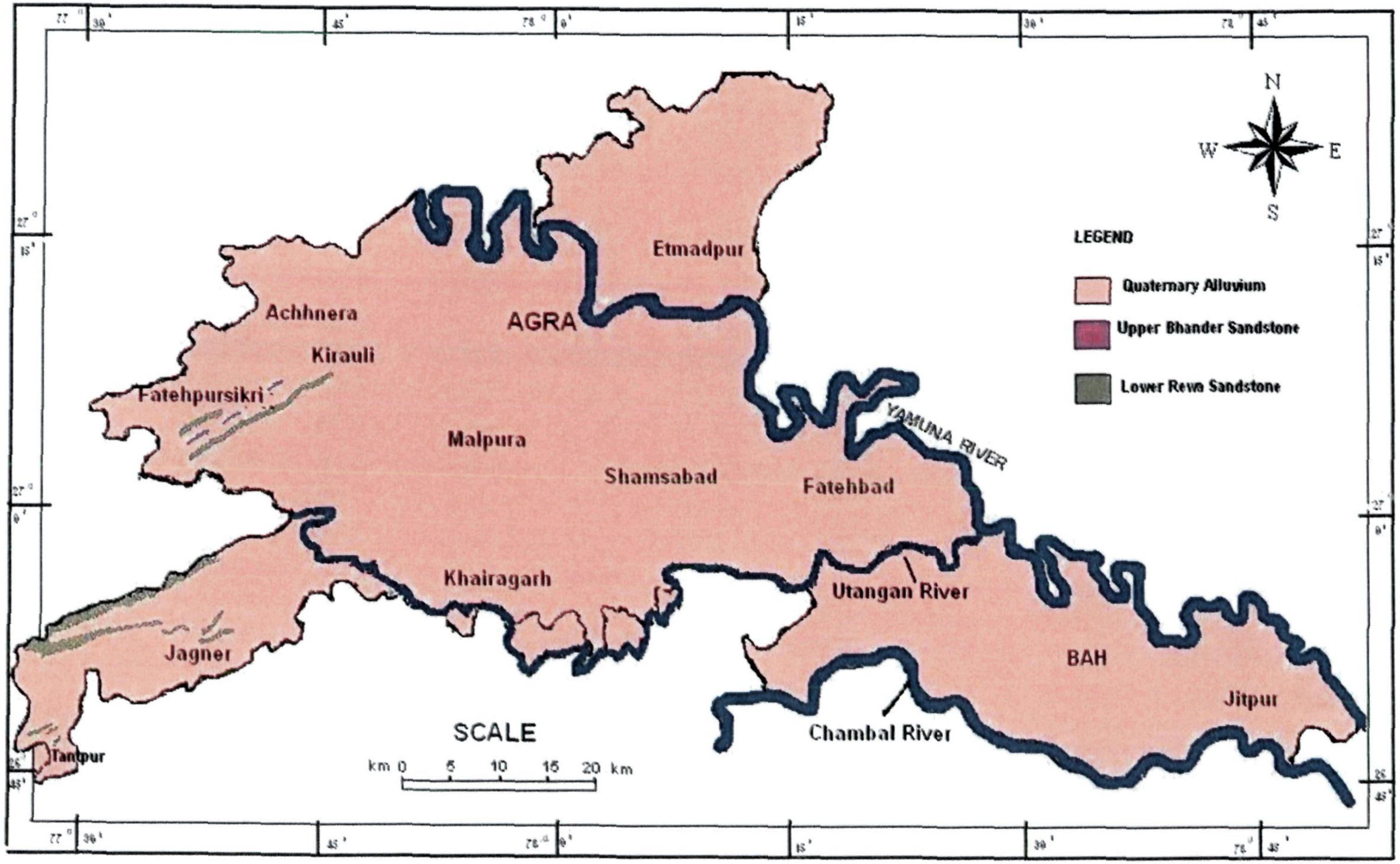

Figure - 4.1 Geological map of Agra District, Uttar Pradesh of gravel, sand, silt, clay and kanker in various portions. In the lower part just above the basement, thick horizons of arkosic gravel and coarse sand are present. They are followed by clay kankar (calcreate nodules) succession with thin, fine sand interaction. The top most 10 meter layers are invariably made up of clay with kankar and distinct calcreate horizon.

The alluvium deposit of Agra district are further classified into two sub-division, Khandar (Newer Alluvium, recent/Holocene Deposit) and Bhanger (Older Alluvium, Pleistocene Deposit)

i) Khadar (Newer Alluvium, Recent/Holocene Deposit)

Khadar lands are confined to the terraces and the floodplains of the river and their tributaries. They are formed by the erosive action of rivers. The main channels of the river are confined to well defined valley and the flood level of the water is well below the general level of the country. The prevailing soils of Khadar are sandy, poor in calcareous matter, light in colour and often micaceous.

The Khadar is deficient in calcareous constitutes and is entirely protected from the salts of soda and magnesia accumulates and form saline and alkaline efflorescence, which reduce the fertility of soil.

ii) Bhangar (Older Alluvium, Pleistocene Deposit)

The most important material in Bhangar is clay, which at places becomes loamer and loam. In this clayey part of alluvium, irregular concretion of *kankar* of various shapes and size are found at different level. These are formed due to the segregation of calcareous material of alluvium deposit into lumps or nodules.

Khadar soils are comparatively less retentive of moisture than the Bhangar soil, but as the subsoil water level is relatively high, there is almost textural uniformity in subsoil. The Bhangar soils are relatively more durable than the Khadar soil.

4.2.1 Structures

In and around the Agra, the rocks belonging to the Vindhyan Supergroup are highly folded and faulted. Heron (1922) maintained two main faults running parallel to NE-SW directions. The earlier extremity of the Great Boundary Fault (GBF) passes from eastern Rajasthan has been traced to about 3 Km west of Agra district.

4.3 Geology of Bah

The study area is a part of the Indo-Gangetic Plain. Bah Tahsil consists of older Alluvium of Middle to Upper Pliestocene age and forms a part of the Indo - Gangetic Alluvium. The nearest Precambrian outcrop lies about 64 km south - west of Bah.

Bah area is underlain by the Quaternary alluvial deposits and no bed rock is met down to depth of about 140m (Pathak, 1968) the deposition of clay is thicker than that of sand in this area. The sand beds however are thick enough to yield economic quantities of water to wells.

A major part of the area is covered by Gangetic alluvial deposits of the quaternary period comprising gravel, sand, silt, clay and kankar in various proportions (Misra, 2005; Misra and Mishra, 2006 and 2007). The thickness of the alluvial cover around the study area ranges from 200 to 250 m. In the lower part just above the basement, thick horizons of arkosic gravel-coarse sand are present. They are followed by a clay-kankar (calcrete nodules) succession with thin, fine sand intercalations. The topmost 10 m are invariably made up of clay with kankar and distinct calcrete horizons (Singh, 1996). River Yamuna act as a lifeline and is the main river flowing through the district. In the study area, the groundwater occurs both in unconfined and confined conditions.

The north Indian plains consist of alluvial deposits through geological ages by great Himalayan Rivers. The nature of the district is of various sizes from big boulders to silt and clay. The arrangement of the bedding and the general form of the surfaces due to sedimentation lay down in gentle inclined layers, which are the principal types of river deposits. The extensive deposits of the very young age are the stratified alluvial accumulation between peninsular India and the southern front of the Himalayas of post tertiary formation and filled up by Pleistocene alluvium.

4.3.1 Subsurface Geology

The geological section exposing subsurface geology (Fig. 4.2) has been prepared from the borehole data of a tube well derived by Uttar Pradesh Jal Nigam, Agra, indicate that the sand and clay beds occur interfringed with each other. This tube well is drilled in Bah up to 164.70m depth where clay-kankar was obtained below sandstone and sand layer.

Depth Interval	Lithology	Litholog
0 - 3.05	Surface Clay	
3.05 - 12.19	Clay Kankar	
12.19 - 18.29	Sandy Clay	
18.29 - 35.06	Clay Kankar	
35.06 - 47.26	Sand	
47.26 - 76.22	Clay Kankar	
76.22 - 80.79	Sand with Clay Kankar	
80.79 - 87.50	Sand	
87.05 - 107.01	Clay Kankar	
107.01 - 115.90	Sand	
115.90 - 121.00	Clay Kankar	
121.00 - 127.82	Sand	
127.82 - 132.90	Clay Kankar	
132.90 - 139.33	Sand	
139.33 - 145.12	Sandstone	
145.12 - 150.08	Sand	
150.08 - 164.70	Clay Kankar	

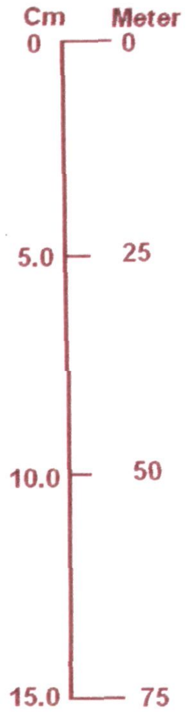

Figure - 4.2 Geological cross section showing subsurface geology under the area of investigation

This litholog shows that clay is commonly found with kankar (calcareous nodules). Clay-kankar succession is found interfringed with sand layer of varying size ranging from very fine to medium at a depth of 76 to 81m. Sand is also found to associated with clay-kankar at a depth of 91m. However kankar has developed more in clay than in sand bed.

Near the surface very thin layer of clay and sand and is found, with the increasing depth it is associated with kankar. As the depth increases this clay-kankar layer hardens and is found interlayered with sand. Topmost 16.29m layer is invariably made up of clay and kankar before first layer of sandy clay. At a depth of 145m sandstone is encountered between two sand layers. Water table is found at 32m depth in the sandy clay. Maximum thickness is attained by clay-kankar succession found at 87.5m depth sandwiched between the sand layers.

Drainage Basin Morphometry

CHAPTER - V
DRAINAGE BASIN MORPHOMETRY

5. General Statement

The morphometric analysis of the drainage basin and channel network play a vital role in understanding the hydrogeological behavior of drainage basin and expresses the prevailing climate, geology, geomorphology and structure etc.The relationship between various drainage parameters and the aforesaid factors are well recognized by Horton, 1945; Strahler, 1957; Melton, 1959; Pakhmode *et al.*, 2003 and Gangalakunta *et al.,* 2004. Recently many workers have used remote sensing data and more precisely data generated using GIS on morphometric parameters (Srivastava and Mitra, 1997; Agarwal, 1998; Nag, 1998; Das and Mukherjee, 2005) have concluded that remote sensing has emerged as a powerful tool and useful in analyzing the drainage morphometry. Further the quantitative hydrogeomorphic analysis of drainage basin was initiated by Langbein, 1947 and followed up by various workers, viz; Golding and Low, 1950; Strahler, 1945, 1952, 1954, 1957 & 1958; Schumm, 1956 and Coats, 1958. The drainage basin or watershed is the fundamental unit in geomorphology within which may be studied the relations between landforms and process that modify them. The size of a drainage basin influences the amount of water yield; the length, shape, and relief affect the rate at which water is discharged from the basin and total yield of sediments; the length and character for stream transport and rate at which water and sediments are discharged.

The objective of the present study is to analyze the morphometric attributes of Yamuna River basin around Bah Tahsil of Agra district. However no systematic work on the morphometry of Agra district has so far been carried out. The study of basin morphometry attempts to relate basin and stream network geometries to the transmission of water and sediment through the basin. The drainage map of the study area (Fig.5) was prepared and 4 sub-basins namely Pidhura, Batesar, Balarpur and Pariar (Fig.5.1) were selected for detailed morphometric analysis.

Detailed morphometric study is carried out and discussed with respect to the linear aspects, areal aspects as well as relief aspects of the drainage network.

5.1 Linear Aspects of the Drainage Network

The linear aspects include stream order, stream length, mean stream length stream length ratio and bifurcation ratio and the results of the analysis are given in Table-11 & 12 and discussed below.

5.1.1 Stream Segments, and Stream Order (Nu)

The basic element of stream networks is the stream segment, or link. This is a section of stream channel between two channel junctions or, for "fingertip" tributaries, between a junction and the upstream termination of a channel.

The designation of stream orders is the first step in drainage basin analysis and expresses the hierarchical relationship between segments, which is a fundamental property of stream networks as it related to the relative discharge of a channel segment. In the present study the number of stream ordering is carried out using the method given by Strahler (1964). Accordingly a stream segment with no tributaries is designated as a first order segment. A second order segment is formed by the joining of two first order segments, a third order segment by the joining of two second order segments and so on.

The order wise stream numbers of four sub-basins are counted and presented in Table-11 indicates that the sub-basin- I and II are of third order whereas; III and IV are of fourth order. It is also observed that the numbers of stream segments present in each order are counted shows that the number of stream segments decreases as the stream order increases. This observation verify the Horton's Law (1945) of stream number i.e. the number of stream segments of each order forms an inverse geometric sequence with order number. This geometric relationship is shown graphically in the form of straight line when the log value of these variables (stream order and stream number) show an inverse relationship (Fig.5.2) while the semi log plot of stream order and mean stream length (Fig.5.3) show a positive relationship.

5.1.2 Bifurcation Ratio (Rb)

The bifurcation ratio is the ratio of the number of stream segments of given order to the number of segments of next higher order. Horton (1945) and Schumm (1956) considered the bifurcation ratio as an index of relief and dissection.

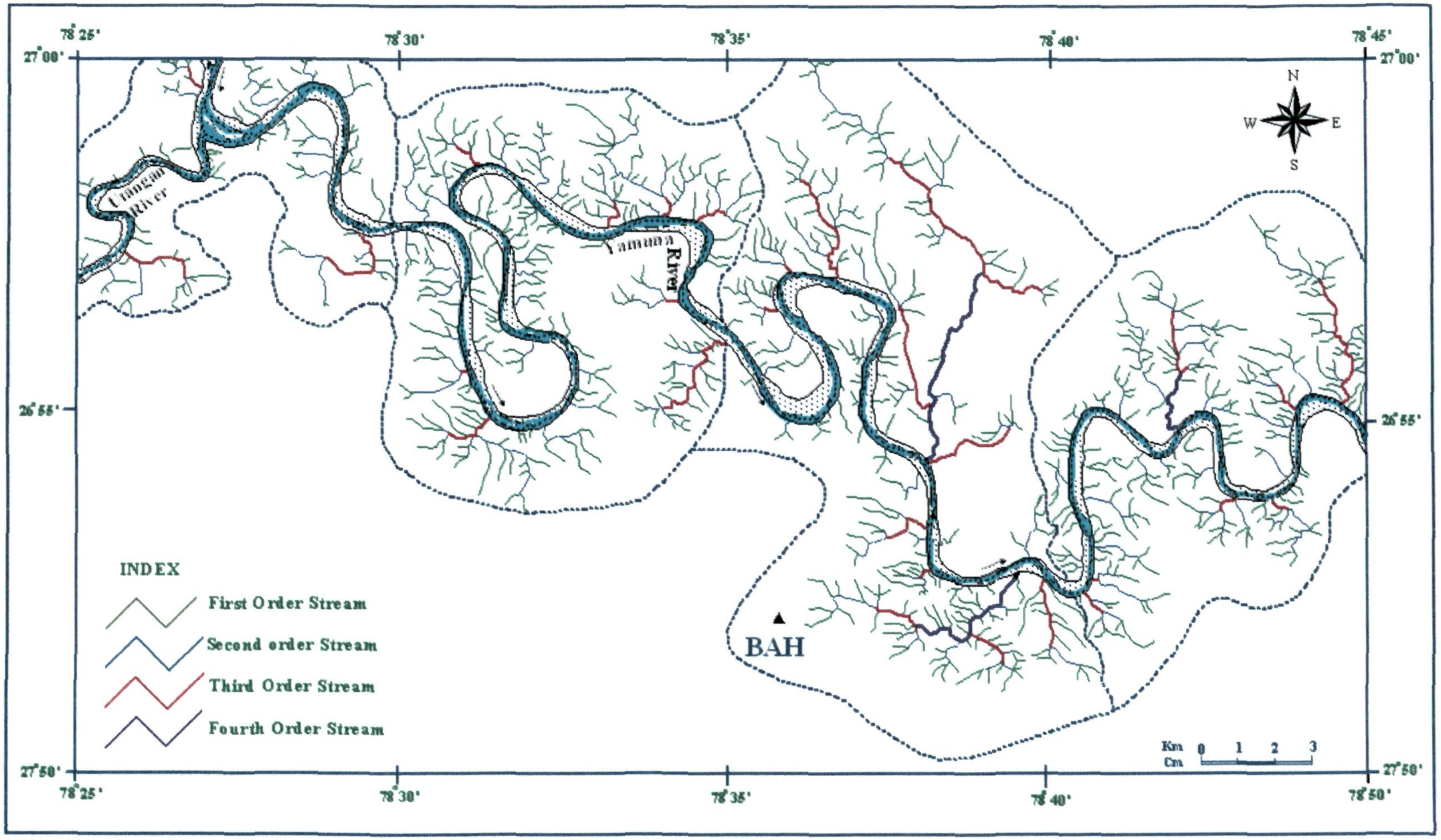

Figure - 5 Drainage map of the study area

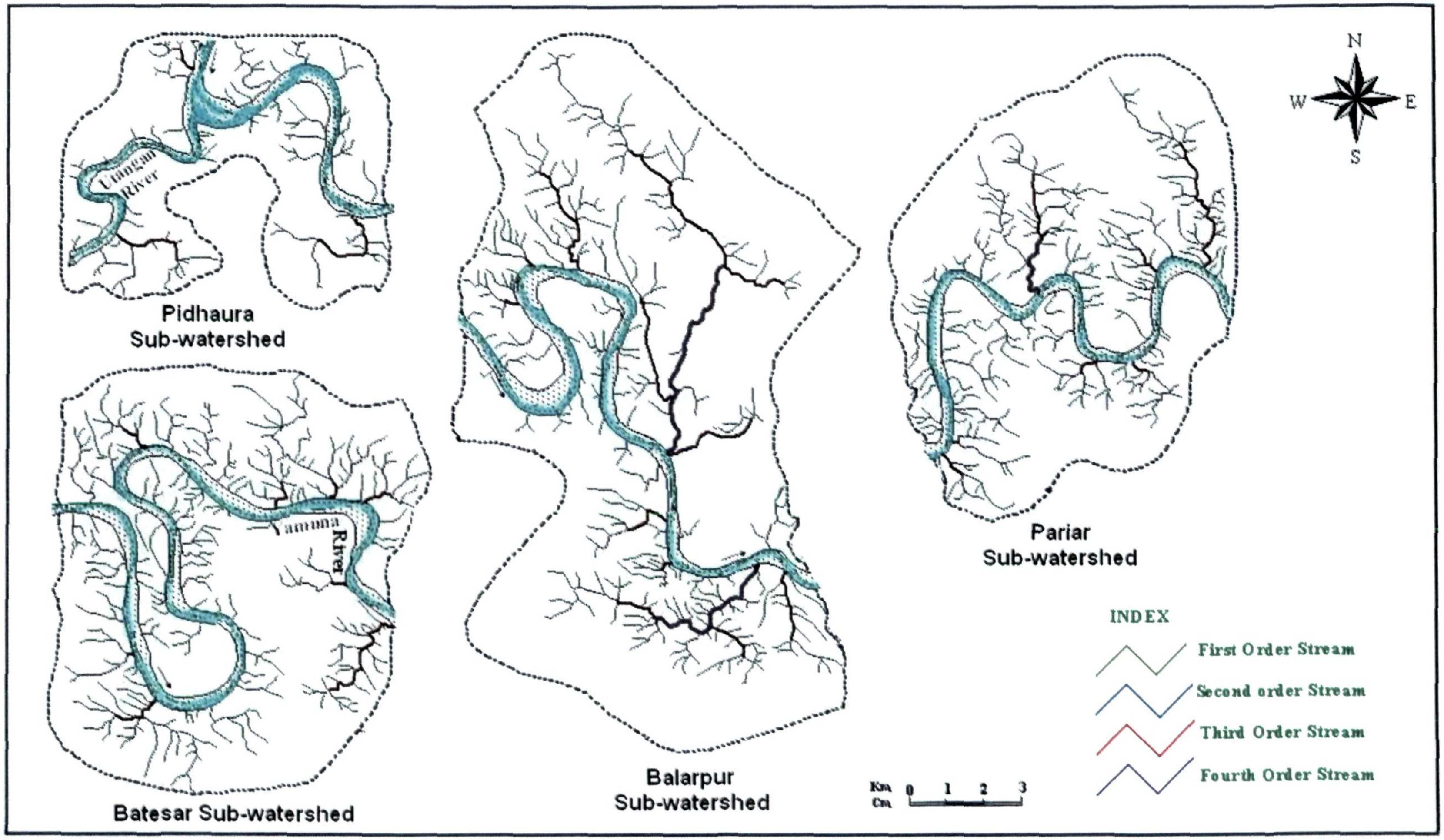

Figure - 5.1 Split sub-basins

It is well demonstrated (Strahler, 1957) that bifurcation ratio shows a small range of variation for different regions or for different environment except where geological control dominates. It has been found that the bifurcation ratios characteristically range between 3.0 and 5.0 for watershed in which geology is reasonably homogeneous and not suffered by the structural disturbances.

Mathematically Rb can be defined as

$$\mathbf{Rb = Nu / Nu{+}1}$$

Where,

Nu: Number of stream segments present in the given order.

The bifurcation ratio for different sub-basins have been determined and tabulated in Table-11. It is observed that the values of bifurcation ratio are variable from one order to its next order and deviates from 3.2 to 4.3. These irregularities are possibly dependent upon the drainage basin. The lower values of Rb are characteristics of the sub-basin which have suffered less structural disturbances (Strahler, 1964) and the drainage patterns have not been distorted. Furthermore the low Rb values in the area of study indicate areas with uniform surficial materials where geology is reasonably homogeneous character of the basin. The semi log plot of stream order vs stream number (Fig.5.2) has been drawn and a straight line was fitted through these points. The slope of these lines gives the bifurcation ratio and indicates an inverse relationship between stream order and stream numbers.

5.1.3 Stream Length (Lu) and Stream Length Ratio (Rl)

It is the length of stream of various orders from their mouth to drainage divide. The stream length has been computed based on law proposed by Horton (1945). In the study area the values of stream length varies from 1.90 to112.62 Km (Table-12).

Mean Stream length (Lsm) is calculated by dividing the total stream length of order 'U' and number of stream of segment of order 'U'.

$$\mathbf{Lsm = Lu / Nu}$$

Where,

Lu: mean stream length of a given order (km)

Nu: Number of stream segments

Mean length of a stream channel segment of order 'U' is a dimensional property, revealing the characteristic size of component of drainage network and its contributing basin surface (Strahler, 1964).

Table - 11 Stream order, stream number and bifurcation ratio.

Stream Order	Pidhaura		Batesar		Balarpur		Pariar	
	Stream No.	Bifurcation Ratio	Stream No.	Bifurcation Ratio	Stream No.	Bifurcation Ratio	Stream No.	Bifurcation Ratio
I	88.0	3.2	224.0	4.3	224.0	4.2	202.0	4.1
II	25.0	8.3	50.0	6.0	53.0	3.7	48.0	5.3
III	3.0	--	8.0	--	13.0	6.5	8.0	4.0
IV	--	--	--	--	2.0	--	1.0	--
Rbm		5.8		5.16		4.78		4.48

Table - 12 Stream order, stream length and mean stream length.

Stream Order	Pidhaura			Batesar			Balarpur			Pariar		
	Stream Length (Km)	Mean Stream Length (Km)	SLR	Stream Length (Km)	Mean Stream Length (Km)	SLR	Stream Length (Km)	Mean Stream Length (Km)	SLR	Stream Length (Km)	Mean Stream Length (Km)	SLR
I	32.50	0.37	1.86	99.75	0.44	1.34	112.62	0.50	0.98	93.00	0.46	1.41
II	17.25	0.69	3.49	29.60	0.59	1.95	26.15	0.49	3.10	31.00	0.65	1.72
III	7.25	2.41		9.25	1.15		20.00	1.53	2.97	8.95	1.12	1.69
IV							9.10	4.55		1.90	1.90	

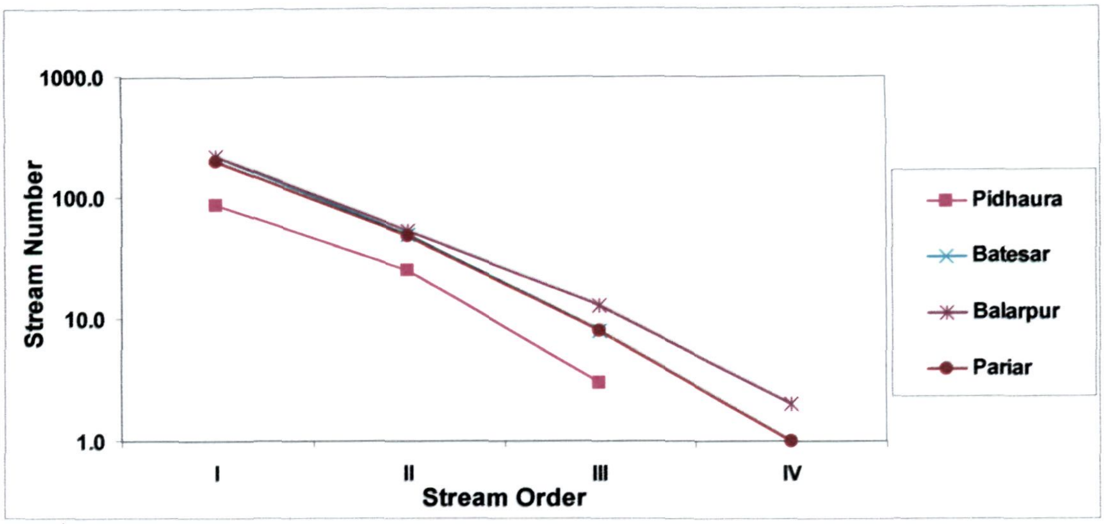

Figure - 5.2 Semi log plots of stream order vs stream number

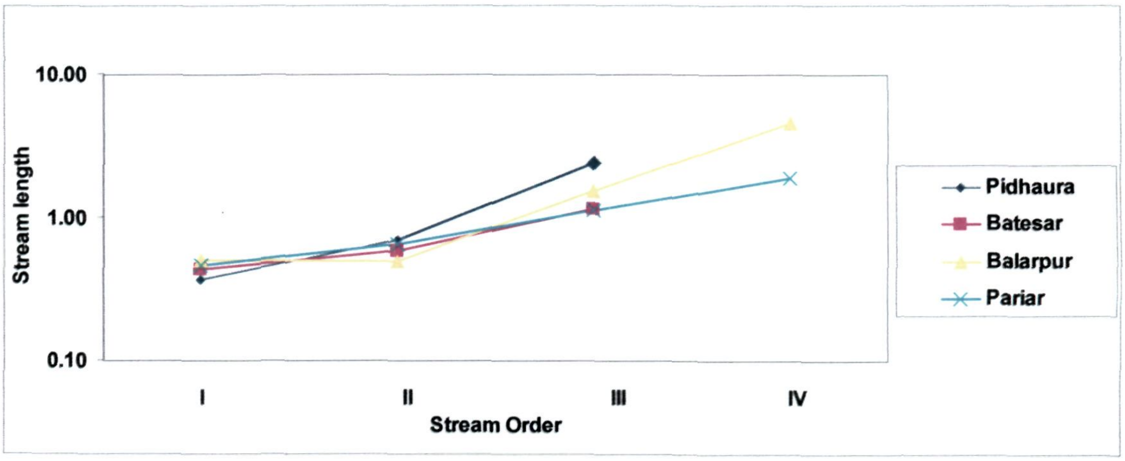

Figure - 5.3 Semi log plots of stream order vs mean stream length

Stream Length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order and is determined by the formula

$$\mathbf{RL = Lu / Lu\text{-}1}$$

Where,

Lu: mean stream length of a given order (Km)

The values mean stream length (Table-12) indicate that Lsm varies from 0.37 to 4.55 km. and the Lsm values of any given order are found greater than that of the lower order and less than that of its next higher order in all the sub-basins except sub-basin III (Balarpur), which is abnormally increased possibly due to variation in the slope and topography.

The stream length ratio can be defined as the ratio of the mean stream length of a given order to the mean stream length of next lower order (Horton, 1945) and having important relationship with surface flow and discharge. The stream length ratio (SLR) between streams of different order in the study area shows variation in SLR (Table -12). Pidhaura and Batesar sub-basins show an increasing trend in the length ratio from lower order to higher order, indicating their mature geomorphic stage, whereas the variable SLR values of Balarpur and Pariar sub-basins from one order to another order indicating their youth stage of geomorphic development.

5.1.4 Length of Overland Flow (Lg)

Horton (1945) defined length of overland flow as the length of flow path, projected to the horizontal of non channel flow from point on the drainage divide to a point on the adjacent stream channel. He further noted that Lg is one of the most important independent variable affecting both hydrologic and physiographic development of drainage basins. The length of overland flow is approximately equal to the half of the reciprocal of drainage density.

$$\mathbf{Lg = \tfrac{1}{2} (Au / Lu)}$$

Where,

Au: Basin Area (Km^2)

Lu: mean stream length of a given order (Km)

Lg is the length of water over the ground before it gets concentrated in definite stream channels (Horton, 1945). This factor basically relates inversely to the average slope of the channel and is quiet synonymous with the length of sheet flow to a large degree.

Table-14 show that Lg is less in Batesar and Balapur sub-basins possibly due to high drainage density in these sub-basins as compare to the values of Lg in Pidhaura and Pariar sub-basins. The computed value of all 4 sub-basins varies from 0.30 – 0.40.

5.2 Areal Aspects of the Drainage Network

The areal aspects include basin area, basin shape, drainage density, drainage texture, stream frequency, form factor, circularity ratio, elongation ratio and length of overland flow. *The results are given in Table-13 & 14 and discussed as below:*

5.2.1 Basin Area

A drainage basin is an area, defined by a topographic boundary that diverts all runoff to a single outlet. The topographic boundary that separates runoff between two basins is the drainage divide. The delineation of the drainage basin can be done manually using topographic information. On the other hand, the wide spread availability of elevation data in digital format has bolstered the development of automated tools that can be used to delineate drainage basin and their associated stream network.

The maximum drainage area is covered by the Balarpur whereas Pidhaura sub-basin is characterized by the minimum drainage area.

5.2.2 Basin Shape (Bs)

The shape or outline form of a drainage basin, as it is projected upon the horizontal datum plane of a map, may considerably affect stream discharge.

Horton (1945) described the outline of a normal drainage basin as a pear shape ovoid.

$$\mathbf{Bs = Lb^2 / Au}$$

Where,

Lb: Maximum Basin length (Km)

Au: Area of the Basin (Km^2)

There are various parameterse used to define the shape of the basin viz; Elongation Ratio (Re), Form Factor (Rf) and Circularity Ratio (Rc). These parameters are discussed below and graphically presented in Fig.5.4.

a) Elongation Ratio (Re)

Schumm (1956) defined elongation ratio as the ratio of diameter of a circle of the basin.

A circular basin appear to more efficient in the discharge of run-off than that of an elongated basin (Singh and Singh, 1997). The Re values generally ranges between 0.6 and 1.0 over a wide variety of climate and geologic types. Values near to 1.0 are the characteristics of the region of very low relief, while values in the range of 0.6 -0.8 are usually occurs in the areas of high relief and steep ground slope (Strahler, 1964). These values are further categorized as (a) circular (>0.9), (b) oval (0.9-0.8), (c) less elongated (<0.7).

$$\mathbf{Re} = \frac{\sqrt{\mathbf{Au}/\pi}}{\mathbf{Lb}}$$

Where,

Au: Area of the Basin (Km^2)

Lb: Maximum Basin length (Km)

The Re values in the study area vary between 0.69 and 0.84 (Table-13), which indicates slightly moderate to moderate ground slope. The lowest value in case of Balarpur sub-basin indicate high relief and moderate slope whereas sub-basins Batesar and Pariar having values 0.84 and 0.83 respectively, indicate almost plain land with moderate to low relief and low slope.

b) Circularity Ratio (Rc)

Miller (1953) define circularity ratio as the ratio of the basin area to the area of a circle having the same circumference perimeter as the basin, which is dimensionless and expresses the degree of circularity of the basin.

$$\mathbf{Rc} = \frac{\mathbf{4\pi Au}}{\mathbf{P^2}}$$

Where,

Au: Basin Area (Km^2)

P: Perimeter of the basin (Km)

Rc is dimensionless and express the degree of circularity of the basin. Rc values (Table-13) in the Pidhaura and Balarpur sub-basins vary between 0.48 - 0.49, indicate that these sub-basins are more or less elongated. In Batesar and Pariar sub-basins, Rc values ranges between 0.71 – 0.89, indicate that these are more or less circular and are characterized by high to moderate relief and drainage system seems to be structurally controlled. This also indicates the tendency of small drainage basin in homogeneous geologic materials to preserve geometrical similarity.

d) Form Factor (Rf)

The form factor is the ratio of basin area to square of the basin length and is a quantitative expression of drainage basin out line (Horton, 1932) and can be obtained by using the formula:

$$\mathbf{Rf = Au / Lb^2}$$

Where,

Au: Area of the Basin (Km^2)

Lb: Maximum Basin length (Km)

The Rf values (Table-13) *in the study area varies from 0.38 to 0.55, indicates* that the sub-basin Balarpur is elongated in shape whereas the higher values of form factor in the remaining sub-basins, indicates that they are slightly elongated to circular in shapes.

5.2.3 Drainage Density (Dd)

The drainage density is an important indicator of the linear scale of landform element in stream eroded topography, introduced by Horton (1932) and is define as the total length of stream of all order per drainage area and may be an expression of the closeness of spacing of channels.

$$\mathbf{Dd = \sum Lu / Au}$$

Where,

Lu: Total stream length of all orders (Km)

Au: Area of the Basin (Km^2)

High drainage densities usually reduce the discharge in any single stream, more evenly distributing runoff and speeding runoff into secondary and tertiary streams. Areas with high drainage density means that it takes water a while for water to drain to a primary stream and time to arrive at secondary streams. Where the drainage density is very low, intense rainfall events are more likely to result in high discharge to a few streams and therefore a greater likelihood of "flashy" discharge and flooding in humid areas of low drainage densities (such as 3-4 miles per square mile) suggest resistant bedrock in humid areas; high drainage densities (such as hundreds of miles per sq. mile) suggest highly erodable surficial materials.

In general low drainage density is favoured in regions of highly permeable *subsoil material, under dense vegetative* cover and where relief is low whereas, the high drainage density is favoured in regions of weak or impermeable subsurface materials, sparse vegetation and mountain relief (Chow, 1964). The low drainage density is also indicative of relatively long overland flow of surface water.

Langbein (1947) recognized the significance of Dd as a factor determining the time of travel by water and he also suggested a drainage density varying between 0.55 and 2.09 Km/Km^2 in humid region with an average density of 1.03 Km/Km^2.

According to Nag (1998), low drainage density generally results in the areas of highly resistant or permeable sub-soil material, dense vegetation and low relief.

The drainage density in the study area varies between 1.29 and 1.65 Km/Km^2 indicating low drainage density (Table-14), suggests the region has highly permeable subsoil and dense vegetation cover.

5.2.4 Stream Frequency (Fs)

Horton (1932) defined stream frequency as the number of stream segment per unit area and is given as:

$$\mathbf{Fs = \sum Nu / Au}$$

Where,

Nu: Total number of streams in the basin

Au: Basin Area (Km^2)

Table-14 shows Fs for all four sub-basins of the study area. It is noted that the Fs exhibits positives correlation with the drainage density values of the sub-basins indicating the increase in stream population with respect to increasing in drainage density (Fig.5.5).

5.2.5 Infiltration Number (If)

Infiltration number plays a significant role in observing the infiltration characters of a basin. It is expressed as the product of the drainage density and stream frequency.

$$\mathbf{If = Dd \times Fs}$$

Where,

Dd: Drainage density

Fs: Stream frequency

The If values in the study area ranges between 2.63 and 5.22 (Table-14). These higher values of the infiltration number in the basin clearly indicate low infiltration and high runoff

5.2.6 Drainage Texture (Rt)

The drainage texture is one of the important concepts of geomorphology which show the relative spacing of the drainage lines. Drainage lines are numerous over impermeable areas than permeable areas and are the total number of segments of all order per perimeter of that area. According to Horton (1945), drainage texture is the total number of segments of all order per perimeter of that area.

$$\mathbf{Rt = \sum Nu / P}$$

Where,

Nu: Stream Number

P : Perimeter

Further, Smith (1950) classified drainage density into five different textures. The drainage density less than 2 indicates very coarse, between 2 and 4 is related to coarse, between 4 and 6 is moderate, between 6 and 8 is fine and greater than 8 is very fine drainage. According to this classification drainage texture of Pidhaura and Balarpur having values 3.48 and 5.54 respectively falls under very coarse to coarse drainage texture category while Pariar and Batesar falls under fine drainage texture category with values 6.77 and 8.17 respectively (Table-14).

5.3 Relief Aspects of Channel Network and Contributing Slopes

The relief aspects determined include relief ratio, relative relief and ruggedness number. The results of the analysis are given in Table-15.

5.3.1 Channel Gradient

The channel gradient in the present study was determined by dividing the difference in altitude from source to mouth by horizontal distance along the river.

5.3.2 Maximum Basin Relief (H)

The maximum basin relief is the elevation difference between basin mouth and the highest point on the basin perimeter. It is very important factor to obtain the potential energy of drainage system. The values of maximum basin relief for drainage basins were determined are given in Table-15.

5.3.3 Relief Ratio (Rh)

The relief ratio is obtained when basin relief "H" is divided by the maximum basin length (Lb), results in a dimensionless ratio which is equal to the tangent of the angle formed by two planes intersecting at the mouth of the basin called relief ratio

Table - 13 Shape parameters of different drainage sub- basins.

S.No	Name of Sub-basin	Area (Km^2)	Maximum Basin Length (Km)	Basin Perimeter (Km)	Elongation Ratio (Re)	Circularity Ratio (Rc)	Form Factor (Rf)
1	Pidhaura	44.00	10.00	33.25	0.74	0.49	0.44
2	Batesar	84.62	12.40	34.50	0.84	0.89	0.55
3	Balarpur	136.38	19.00	60.00	0.69	0.48	0.38
4	Pariar	81.93	12.25	38.25	0.83	0.70	0.55

Table - 14 Drainag density, stream frequency, infiltration number and drainage texture.

S. No.	Name of the Sub-basin	Drainage Density (Dd)	Stream Frequency (Fs)	Infiltration Number (If)	Length of Overland Flow	Drainage Texure (Rt)
1	Pidhaura	1.29	2.63	3.39	0.39	3.48
2	Batesar	1.63	3.33	5.43	0.31	8.17
3	Balarpur	1.23	2.14	2.63	0.40	5.54
4	Pariar	1.65	3.16	5.22	0.30	6.77

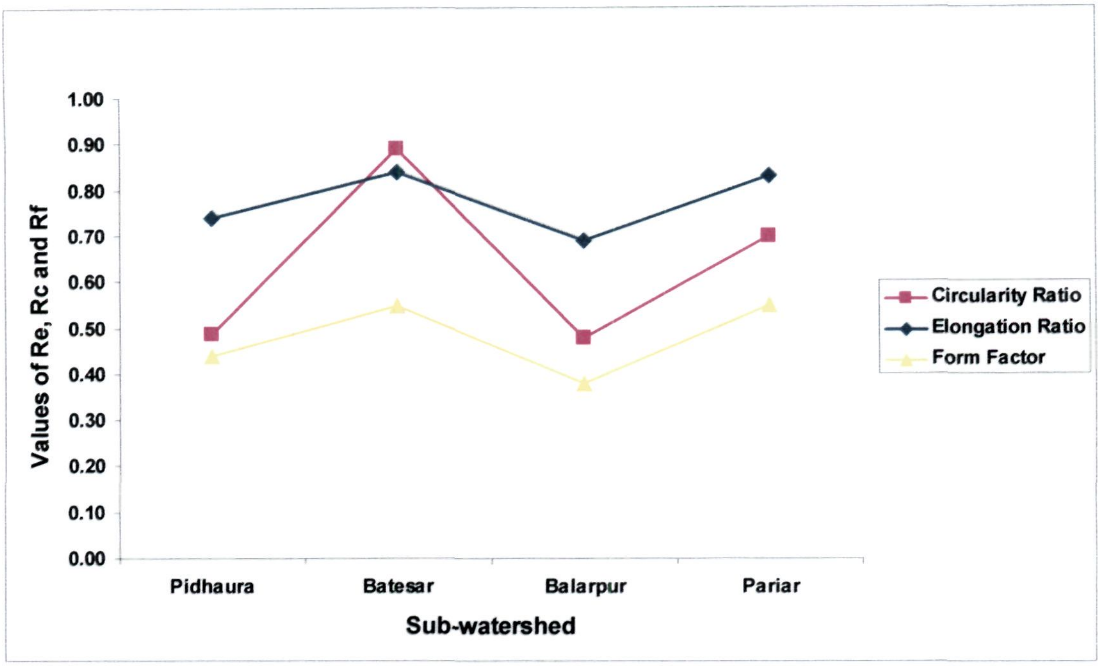

Figure - 5.4 Plots of shape parameters of all four sub-basins

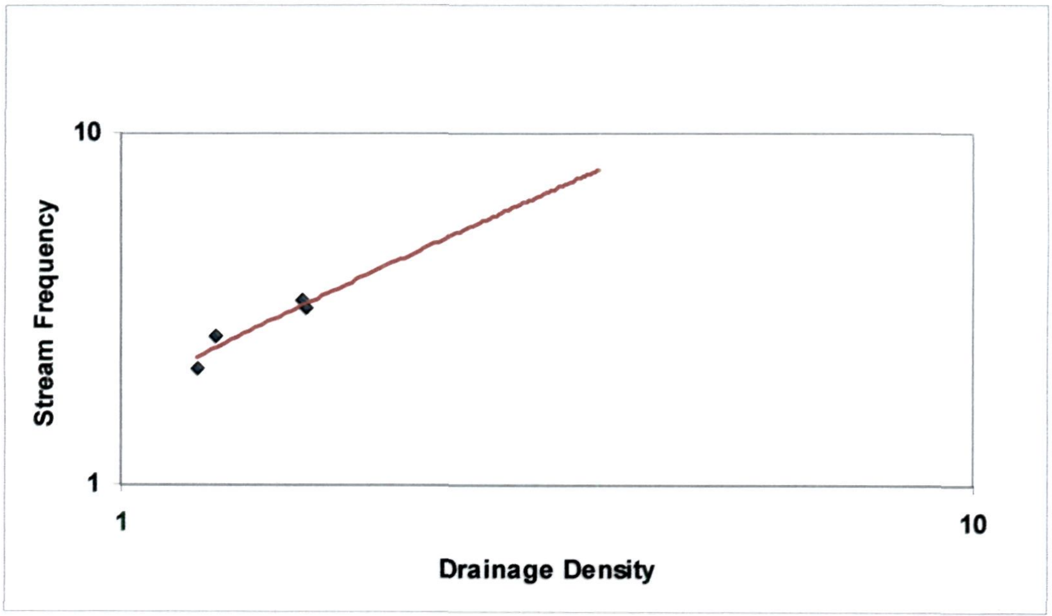

Figure - 5.5 Semi log plots of drainage density vs stream frequency measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin (Schumm, 1954).

Relief ratio measures the overall steepness of a drainage basin and is an indicator of the intensity of erosion process operating on slope of the basin. Schumm (1956) measured relief ratio as the ratio of maximum basin parallel to the principal drainage line. Melton (1957) used relative relief expressed in per cent.

$$Rh = \frac{H}{Lbmax}$$

Where,

H : maximum basin relief

Lbmax: maximum basin length (Km)

The low Rh values in the area of interest, ranges from 0.0017 (Pidhaura) to 0.0031 (Pariar).

5.4.4 Relative Relief (Rhp)

This term was used by Melton, 1957 and the relative relief is given by:

$$Rhp = \frac{100\,H}{P}$$

Where,

H : Maximum basin relief

P : Perimeter of the basin (Km)

The relative relief of different drainage basins were determined and presented in Table-15 and it is noted that Balarpur drainage basin has got maximum relative relief and Pariar sub-basin has got the minimum value.

5.4.5 Ruggedness Number (HD)

It is the product of maximum basin relief H and drainage density Dd, where both parameters are in the same unit. Extreme high values of ruggedness number occur when both variables are large, this is, when slope are not only steep but long as well (Strahler, 1958).

$$HD = H * Dd$$

Where,

H: Maximum basin relief

Dd: Drainage density

In the present study the value of ruggedness no. is low, indicating gentle slope (Table-15).

Table - 15 Parameters of gradient aspect of various sub-basins.

Name of Sub -basin	Elevation		Max. Basin Relief (Km)	Relief Ratio (m)	Relative Relief (Rhp)	Ruggedness Number (HD)
	Highest point (m)	Lowest Point (m)				
Pidhaura	160	143	0.017	0.0017	0.051	0.022
Batesar	162	140	0.022	0.0018	0.064	0.036
Balarpur	160	140	0.02	0.0011	0.033	0.025
Pariar	158	120	0.038	0.0031	0.081	0.063

Hydrogeology

CHAPTER - VI

HYDROGEOLOGY

6 General Statement

The Indo-Gangetic alluvial plain is one of the largest groundwater repositories of the earth. For several decades, the drainage basin of the Ganga Plain has been used for the disposal of domestic and industrial wastes, which has adversely affected the quality of water, sediments and agricultural soil of the plain (IUGG, 2003). The water potential of the study area is the main source of surface and groundwater, which experiences very low annual precipitation. Since no comprehensive and scientific investigations have been carried out in the region so far, as a part of complete hydrological appraisal of the watershed, informations on baseline hydrological characteristics and spatio-temporal aspects of water resources are not available. In the agricultural sector, the consumption of water is also very high. Since the agricultural sector is increasing by leaps and bounds, the demand for irrigation water is increasing, but due to the saline nature of groundwater in some parts, it cannot be used for irrigation purposes.

Comprehensive hydrogeological studies using remotely sensed data have been carried out in various parts of the country by number of workers viz; Pathak, 1984; Raju, 1984; Srinivasan, 1988; Narsiman, 1990; Sarma and Saraf, 2002; Agarwal *et al.*, 2004 and Trivedi *et al.,* 2005. Estimation of Ground Water Resources of Uttar Pradesh has been carried out in a joint venture of the Central Ground Water Board and the Ground Water Department, U.P. to judge replenishable ground water potential on districtwise basis. The blocks of different districts were categorized as Over Exploited, Critical and Semi-critical. The estimates for Agra (alluvial area) categorize Bah under Semi-critical category. Most of the blocks of Agra district come under safe category, except Etmadpur and Fatehabad which fall under Critical and Semi-critical category (http://cgwblucknow.up.nic.in/).

The large-scale deforestation, mainly due to urbanization, fuel and fodder needs, and unscientifically managed agricultural practices in Bah Tahsil are some of the major human transformation processes that have been causing reduction in groundwater recharge through increased overland flow and declining rate of infiltration.

6.1 Occurrence of Groundwater

The aquifers in the area belong to the huge aquifers of Indo-Gangetic alluvial plain and the groundwater occurs in both the confined and unconfined conditions.

A major part of the area is covered by Gangetic alluvial deposits of the Quaternary period comprising gravel, sand, silt, clay and kankar in various proportions (Misra 2005; Misra and Mishra 2006). The thickness of the alluvial cover around the study area ranges from 200 to 250 m. The geological cross section modified and reconstructed after Pathak, 1968 (Fig.6 and 6.1) and records of CGWB Agra (Table-16), shows that there are two distinct sand horizons in the eastern end. In the central portion, however, sand beds thin down and thickness of clay bed increases. Kankar has developed more in clay that in sand beds which provide permeability to clay resulting in the occurrence of groundwater in these beds as evident form the borehole data. There are some thin beds of kankar which vary from few centimeters to about 4 meters.

The topmost 10 m layers are invariably made up of clay with kankar and distinct calcrete horizons (Singh, 1996). The deposition of clay is thicker than that of sand in the study area. The sand beds, however, are thick enough to yield economic quantities of water wells.

6.2 Depth to Water Table

The water table in the entire Bah Tahsil varies between 24.30m in Manikpura village to 38.96m in Mau village. However in the ravines on either side of the Utangan, Yamuna and Chambal Rivers, the water table is deepened and ranges between 31.55m and 39.00m.

A few wells measured in the area show that depth-to-water in the wells nearer to river is greater in comparison to those in the interior. The river is deeply entrenched and is fed by effluent groundwater (Pathak, 1968).

6.3 Groundwater Movement

Groundwater movement follows the surface topography which is from west to east on right bank and from east to west on the left bank of Yamuna River. The Yamuna River appears to be effluent in nature except in monsoon period where it forms bank storage.

Table - 16 Hydrogeological details of some tube wells in Bah Tahsil.

S. No.	Toposheet No.	Location of well (Fig. 6)	Total Depth of Boring (m)	Depth to water level below land surface (m) in May 2009
1	54 J/5	Nayabas	107.25	32.00
2	54 J/5	Gopalpura	120.97	26.50
3	54 J/9	Bah	124.80	31.36
4	54 J/9	Baidpura	139.97	34.80
5	54 J/9	Sijwaipura	77.99	37.50
6	54 J/9	Naipura	138.32	38.60

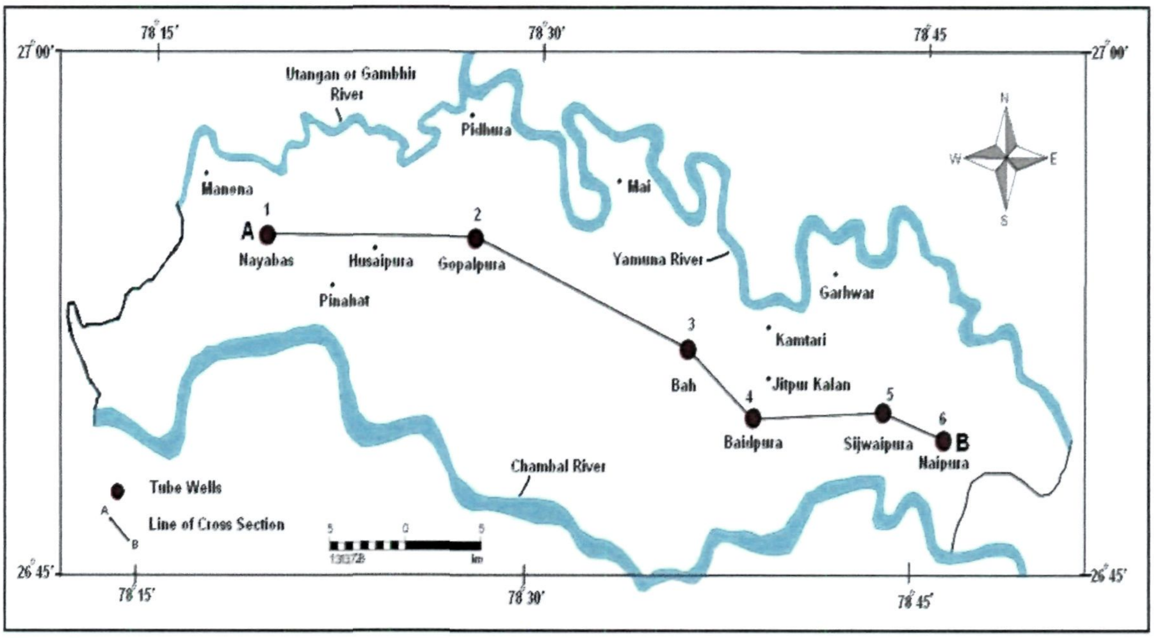

Figure - 6 Map of Bah Tahsil showing location of tube wells and line of cross section A-B

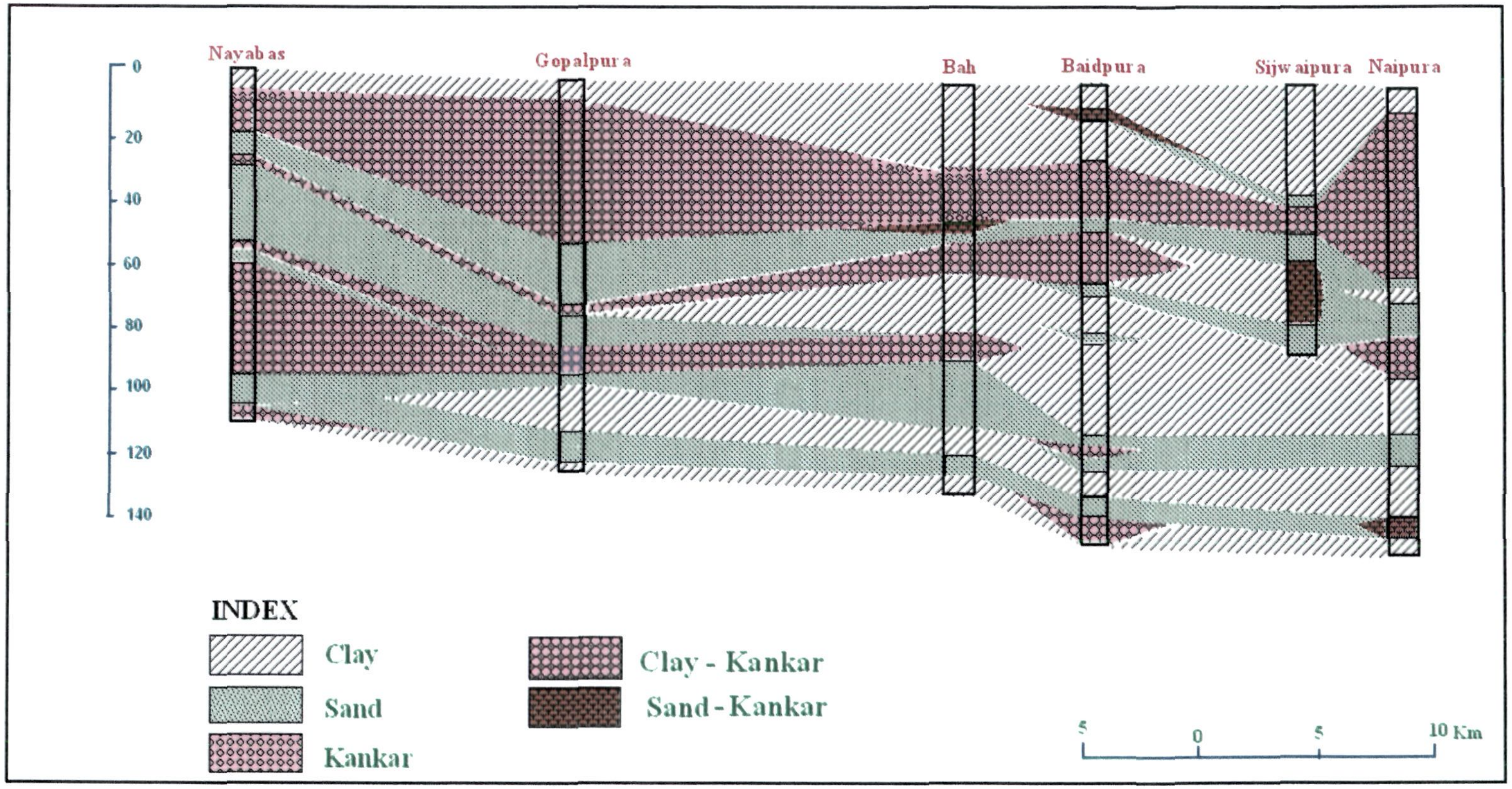

Figure - 6.1 Geological cross section along the Bah Tahsil (Line A-B, in Fig.6) showing the correlation of aquifers

However, there are some local variations in groundwater movement due to local changes in form and slope of topography. Hydraulic gradient is also different on the left and right banks due to the variation in ground flow and other related governing factors (Mukherjee and Rai, 1997).

6.4 Recharge and Discharge of Groundwater

The principal source of groundwater in the area is rainfall. Ponded areas, which come into existence during the monsoon period, also actively impart to the ground water. Direct seepage from the irrigation canals as well as applied irrigation also actively contributes to the groundwater recharge in the area. Quantitative data in regard to the seepage of water from canal is lacking.

The discharge of ground water occurs in the area by effluent seepages to the Yamuna, Chambal and Utangan Rivers. Natural discharge also takes place by springs issuing out from a zone two meters in width along the Chambal River south of Pinahat. In the study area wherever the groundwater is close to the surface, groundwater is discharged into the atmosphere by evapotranspiration and is lost by sub-surface flow to the adjacent area.

6.5 Groundwater Quality

The entire Agra district is facing problems related to water quality. Even in Agra city, the groundwater environment is plagued by the dual ills of saline water occurrence below 30/40 mgbl as well as the sporadic presence of fluorides and nitrates much above the permissible limits (*http://www.cgwblucknow.up.nic.in/*).

A detailed water quality analysis was carried out by Misra and Mishra (2007) in the Quaternary aquifer system of the marginal alluvial plain (Ganga Plain) in Bah Tahsil. They analyzed electrical conductivity of 50 samples each from dug wells, hand pumps and tube wells for the study of salinity levels in shallow, intermediate and deep aquifers. Samples were also analyzed for other chemical constituents such as Na^+, K^+, Cl^-, F^- and TDS. The analyses show drastic changes in the salinity levels of shallow, intermediate and deep aquifers. The deep aquifers are more saline compared to the shallow and intermediate aquifers. On the contrary, the concentration of chemical constituents such as Na^+, K^+, Cl^- and F^- was more in the shallow aquifers compared to the deep aquifers. Moreover, the study suggests that the salinity and concentration of the above chemical constituents also escalate with time in each aquifer. The chemical constituents such as Na^+, K^+, Cl^-, F^- and TDS range from 51 to 165 mg/l, 1 to 14 mg/l, 224 to 1,459 mg/l, 0 to 1.5 mg/l and 750 to 2,650 mg/l, respectively. Over a 3-year period, the salinity levels have sharply increased and the average F level has increased by 0.1–0.3 mg/l.

In past the studies carried out indicate that, the sodicity of Indo-Gangetic Plains have been derived from in-situ weathering of alkali alumino-silicates (Bhargava *et al.,* 1981; Kapoor *et al.,* 1981). The main characteristics of soil horizons of the area are the high content of carbonate, distributed throughout the depth of the profile. In addition, the study area show frequent alternations of mud and clay layers in the subsurface lithology as evident from the geological section (Fig.6.1), act as an impermeable layer, preventing the infiltration and percolation of chemical constituents from shallow to deep aquifers of the region and also have very low hydraulic conductivity (Misra, 2005). All these factors together constitute a favourable condition for the maximum absorption of Na^+, K^+, Cl^- and F^- by the clay minerals in the soil of shallow and intermediate aquifers. Misra and Mishra 2007 attributed canal network, low precipitation and high evaporation due to arid climatic conditions, to the enhancement in groundwater salinity. Through time this increase in salinity levels causes the salts present in the dryland to get mobilized and transported by groundwater, capillary rise, evaporation and leaching. This might result in the accumulation and depletion of salts in the shallow, intermediate and deep aquifers. The salinity level variation in deep aquifers is only marginal and there is a relatively low concentration of constituents like Na^+, K^+, Cl^- and F^-, in deep aquifers as compared to the shallow and intermediate aquifers. Although the concentration of these chemical constituents in a majority of the sites is within the maximum permissible limits, the continuous escalation of these constituents in groundwater can pose a potential health hazard in future (Misra and Mishra, 2007).

Hydrogeomorphology

CHAPTER -VII
HYDROGEOMORPHOLOGY

7 General Statement

The term hydrogeomorphology can be divided into three terms hydro; means water including both surface and groundwater, geo; means the earth and morphology; is the surface expression of the features in the form of landforms. This means that the hydrogeomorphology is dealing with the aspect of water, rock and earth's morphological features (land). According to Sheidegger (1973), the term hydrogeomorphology designates the study of landforms caused by the action of water. By this definition almost entire geomorphology is hydrogeomorphology, because water is the most important agent in forming the landforms.

From the groundwater point of view integration of geological, structural and hydrogeological data with hydrogeomorpholgical data is very much useful to find out the groundwater potential zones with fruitful results. The science relating to the geographical, geological and hydrogeological aspects of water bodies and to changes to these aspects in response to low variations and to natural and human caused events, such as heavy rainfall or channel straightening is the "Hydrogeomorphology" (Babar, 2005).

7.1 Hydrogeomorphology of Agra

Agra is situated on the right bank of river Yamuna and is represented by flood plains of this river with upland marginal alluvium (Rao *et al.,* 2009). The alluvial sediment is a mixture of gravel, sand, silt and kankar in various portions. Alluvium deposits represent the area formed during the Quaternary.

Hydrogeomorphologically Agra district can be divided (Fig.7) into five major units namely alluvial plain, structural valley, valley fills, structural hills and ravines. The alluvial plains are mostly composed of gravel, pebbles, sand and silt. The groundwater prospects appear to be good in this unit. Structural valleys in the region are composed of fine to medium sand, which is highly porous and permeable. In this area, the water table

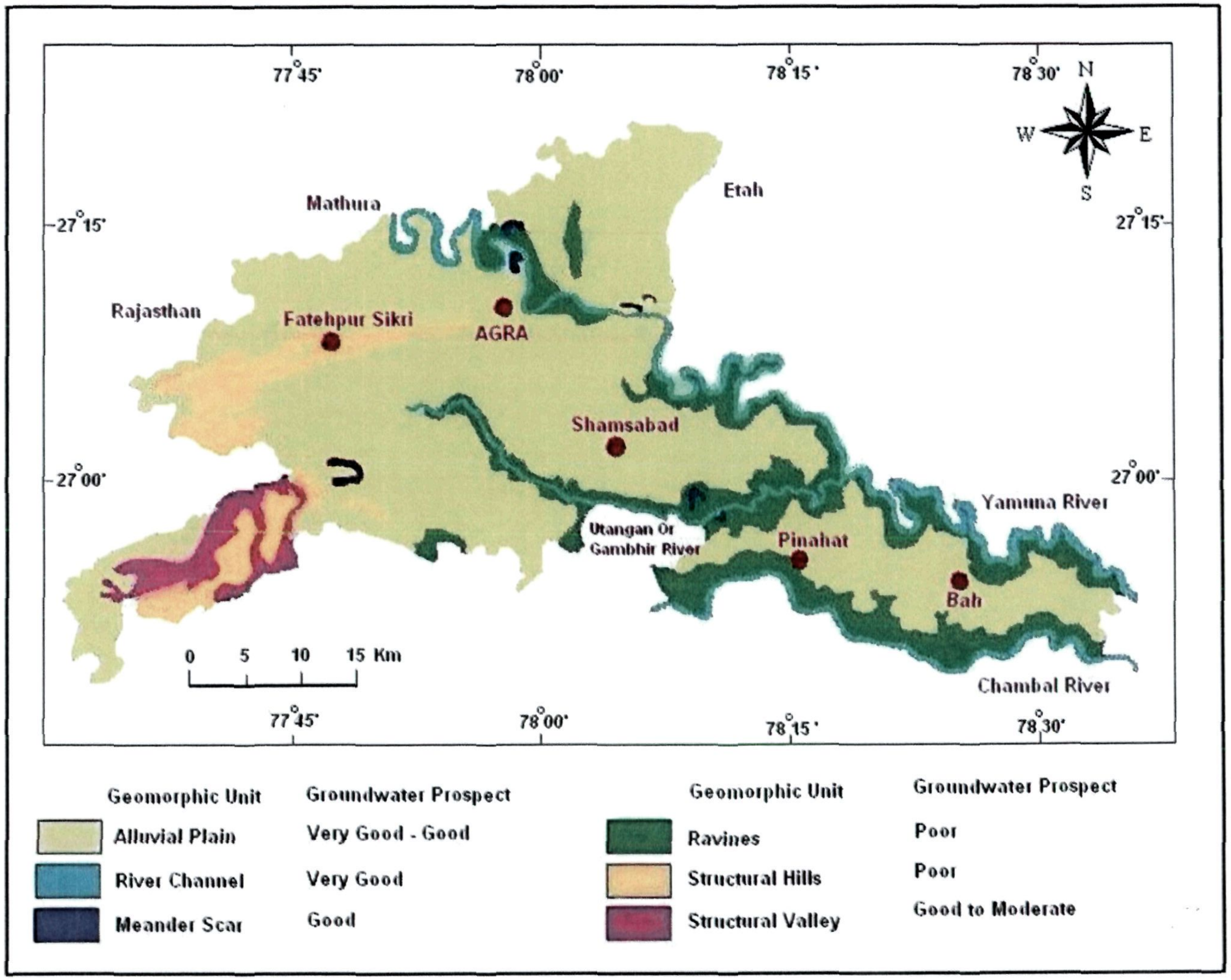

Figure - 7 Hydrogeomorphological map of Agra district, India position ranges from 8 to 15 m. The valley fills mostly lie very close to hilly ranges in the structural valleys, consisting of boulders, cobbles, pebbles, gravels, sand, silt and clay. The shallowest water table position is recorded in these areas. The structural hills are composed of Vindhyan sandstones having undulating terrain. The presence of ravines on either side of River Yamuna and Chambal are the major geomorphic feature.

7.2 Hydrogeomorphology of the Study Area

In recent years increasing use of satellite remote sensing techniques has proved to be most beneficial in hydrogeomorphological mapping and into defining the spatial distribution of different groundwater potential zones based on geomorphology and its associated features (Prithivi, 1980; Sinha *et al.,* 1990; Steven, 1991; Prakash and Mishra, 1991; Shah *et al.,* 1992; Tiwari and Rai, 1996; Ravindran and Jeyaram, 1997; Das *et al.,* 1997; Pradeep, 1998; Thomas *et al.,* 1999; Kumar *et al.,* 1999; Sankar, 2002; Khan *et al.,* 2006 and Rao *et al.,* 2009).

In order to delineate the various hydrogeomorphological features of the study area, the FCC prepared from the band 2, 3 and 4 of Landsat ETM+ data has been visually interpreted by adopting the following criteria for delineation.

1) The overall appearance (morphology)
2) The shape/surface geometry (morphometry)
3) The underlying geology
4) Association of forms

The Hydrogeomorphological map is shown in Fig.7.1 whereas the characteristics of geomorphic units are given in Table-17.

The IRS, Bhuwan and Google Earth data have been used as the supplementary data to make the interpretation easier. Identified hydrogeomorphological units have been subsequently verified in the field. However the detailed methodology for interpretation is given in Chapter-II.

The boundary delineation of landforms has been done on the basis of changes in topographic slopes, relief patterns, surface texture, specific tone, texture size and association characteristics of remotely sensed data.

Hydrogeomorphologically the entire study area has been classified in the following categories:

- **a)** River Channel
- **b)** Point Bar
- **c)** Channel Bar
- **d)** Younger/Recent Alluvium
- **e)** Ravinous land
- **f)** Older Alluvium
- **g)** Meander Scar

a) River Channel

River channels are long and sinusous courses through which water and sediments are transported toward their ultimate destination, the ocean. The channel remain dry during most of the year except the monsoon season that witness a considerable widening of water flow and large scale sediment transport from outside of the meanders towards the point bars lying adjacent to and ahead of the cut bank. The channels in this region experiencing strongly seasonal rainfall, behave as influent during the dry period sustains a steady flow in the channels, which shrink considerable and expose the shallow parts of their beds, i.e. the Bars.

Major rivers identified in the study area are Yamuna, and Utangan. River Yamuna and its tributary Utangan drain the major portion of Bah while Chambal flows in south-western part of the Tahsil. These rivers also form their flood plains and deposit sediments which they carry along with them. These rivers are identified on the satellite imagery from their very dark tone in elongated manner. The river channels cover an area of 16.76 Km^2 (2.56%) and are the discharge zones, groundwater potentiality appears to be good (Photos-7, 11 and 12).

b) Point Bar

A point bar is a depositional feature of streams. Point bars are found in abundance in mature or meandering streams. Point bars are what once called meander bars; are

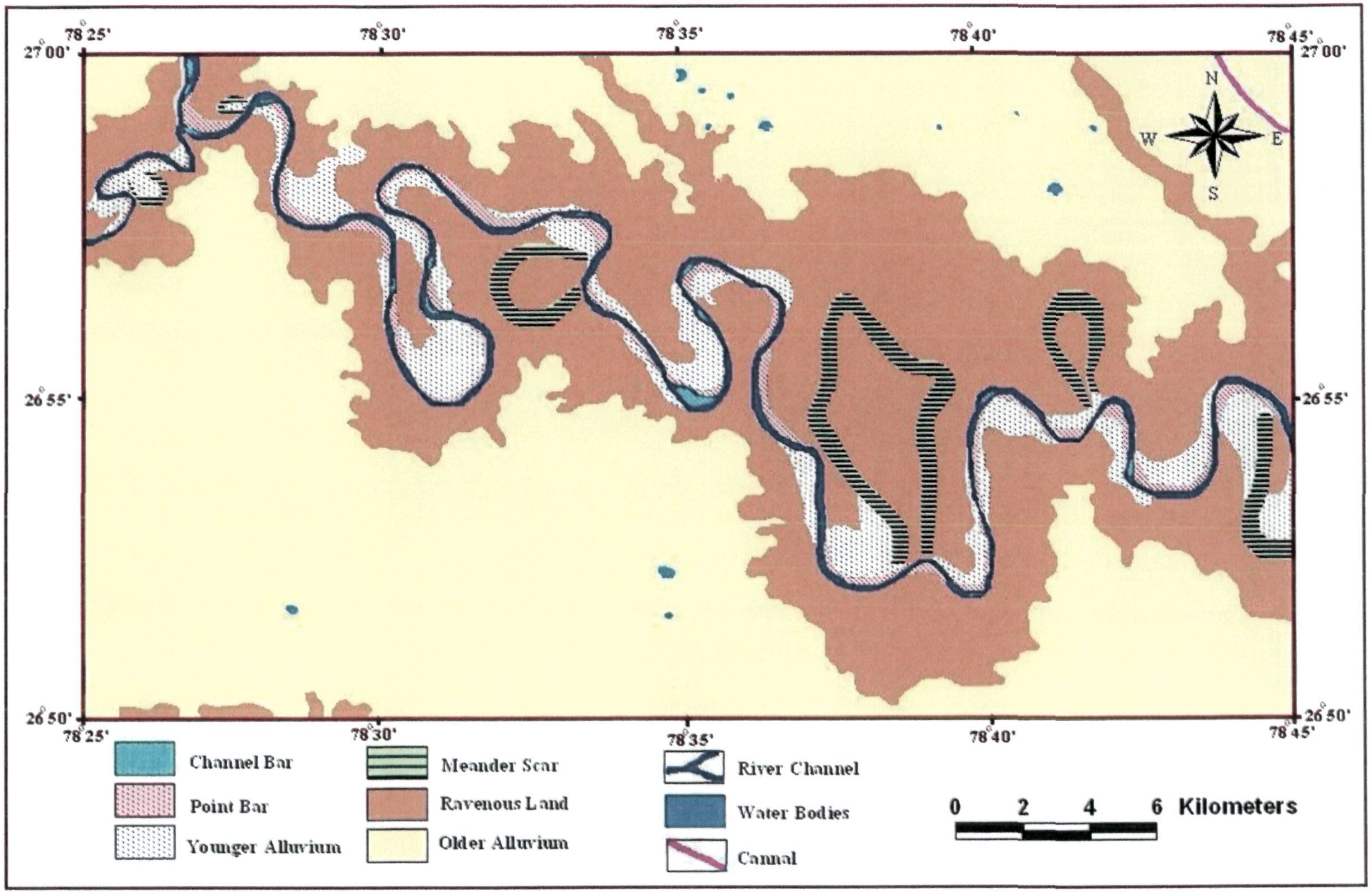

Figure 7.1 Hydrogeomorphological map of the study area

Geomorphic Unit		River Channel	Point Bar	Channel Bar	Younger Alluvium	Ravenous Land	Older Alluvium	Meander Scar
Lithology		Alluvial Plain	Alluvial Plain	Alluvial Plain	Alluvial Plain	Alluvial Plain	Alluvial Plain	Alluvial Plain
Characteristics of Geomorphic Units	Tone/Colour	Very Dark	Light/ Light Blue	Medium/ bluish tint	Light to medium	Very dark to dark	Medium to dark	Dark--very dark/ dark red
	Topographic Expressions / Shape	Linear / Sinuous	Nearly level crescent shape/ Flat Topography	Lenticular / Elongated	Nearly level topography	Upland with grooves/ Undulating Terrain	Gently undulating surface	Linear and Crescent
	Texture	Fine / even	Fine to medium	Medium	Medium, Blocky	Rough and uneven	Mottled	Uniform, Matted/ Coarse
	Association	Flood Plain, Point Bar, Channal bar	River Channel, Flood Plain	River Channel	River Channel, Point Bar	River Channel, Older alluvium, Gullies	Ravenous Land / Waste Land	River Channel, Ravenous Land, Younger Alluvium
	Elevation (Ft)	417 - 471	410 461	421 - 443	418 - 467	445 - 512	495 - 532	419 - 474
	Drainage Pattern	****	Internal drainage	****	Dendritic	Dendritic-Subdendritic to sub-parallel	Dendritic to subdendritic	Dendritic to subdendritic
	Drainage Texture	****	Coarse to very coarse	Coarse to very coarse	Coarse to very coarse	Medium to fine	Coarse to very coarse	Coarse to very coarse
	Landuse Landcover	Waterbody	Cultivation, fallow land, open scrub	Cultivation, open scrub	Agriculture, open scrub and forest cover	Waste land, open scrub	Buildup area, agriculture, waterbodies	Cultivated and fallow land
	Slope	Moderate to steep	Level to very gentle	Level to gentle	Moderate	Moderate to steep	Gentle to moderate	Level to gentle
Hydrogeologic Characteristics		Higly porous and permeable	Higly porous and permeable	Higly porous and permeable	Higly porous and permeable, forming good aquifers	Low porosity and permeable	Higly porous and permeable, forming good aquifers	Higly porous and permeable, forming good aquifers
Ground Water Prospect		Excellent	Very good	Excellent	Very good to good	Poor to Moderate	Good	Excellent
Area (Sq. Km)		16.76	11.17	0.54	31.9	219.19	359.46	16.62
Area (%)		2.56	1.7	0.08	4.87	33.43	54.82	2.54

Table - 17 Different hydrogeomorphological units, their characteristic features and groundwater potentiality.

crescent-shaped and located on the convex side of meander sand grow by individual increments outward into the meander curve.

Point bars are composed of sediment that is well sorted and typically reflects the overall capacity of the stream. These occupy an area of 11.17 Km^2 (1.7%) and are identified by their medium dark tone, fine texture, very gentle slope and association with the river channel. Since these are low lying areas, often overtaken by floods and can accumulate driftwood and other debris during times of high water levels. Due to their near flat topography and the fact that the water speed is slow in the shallows of the point bar they are popular rest stops for boaters and rafters (Photos-3, 5 and 9).

c) Channel Bar

Channel bars in a river begin to form when the discharge is low and the river is forced to take the route of less resistance by means of flowing in locations of lowest elevation. Over time, the river begins to erode the outer edges of the bar, causing it to become a higher elevation than the surrounding areas. The water level decreases even more as the river laterally erodes the less cohesive bank material resulting in a widening of the river and a further exposure of the bar. As the discharge increases, material may deposit about the channel bar since it is an area in the river of low velocity due to its increased elevation than the surrounding areas. During times of extremely high flow, the bars may become covered; only to resurface when the flow decreases. Most channel bars do not remain stable or in one location as seen in the present study. However, vegetation succession on channel bars can increase the stability of the landform. They are commonly composed of sand or gravel and typically occur in braided rivers.

Channel bars are located in the stream course and are perhaps most important characteristics of braided steams, although they are by no means restricted to them as in present study. Number of channel bars occupy relatively small area i.e., 0.54 Km^2 (0.08%) in Yamuna River, in the study area, are identified by their light tone, elongated pattern, medium texture and their association with the river channel (Photos-2a, 2b and 10).

d) Younger / Recent Alluvium

Younger alluvium refers to recent alluvium deposited by the river covering an area of 31.90 Km^2 (4.87%). It is confined to the vicinity of the main channel ~~on the either~~ side.

On the image it produces a characteristic dark red tone due to the presence of high moisture content and abundant vegetation. Most parts of the younger alluvium coincide with the younger terrace. Younger terrace is recent flood plain of Yamuna and is maintained and modified each year by monsoon floods.

e) Ravinous Land

The development of ravines in the catchments of the tributary of Yamuna River such as Chambal, joining on the right bank is very conspicuous and interesting. The ravinous badland of this area are famous for deep gullies with steep gradient. Ravines are very prominent feature found all along the river channels and encroach upon the catchment area by headward growth.

Soil characteristics, upliftment of land and ecological factors have played an important role in the genesis of these ravines. Active gully systems commonly develop in unconsolidated materials due to changing patterns of land use and associated change in catchments hydrology.

Ravines (Photos-1and 6) are identified on imagery due to their association with river channel, dark tone and rough texture, occupying an area of 219.19 Km^2 (33.43%). The ravines are generally formed by intense gulling and certain upliftments of the area, which indicate that the area is tectonically active. The development of ravines along the Yamuna and the Utangan is not as intense and broad as along Chambal and are on an average 3 to 4 km long. They are active agency of soil erosion in these areas. Gully erosion due to river channel trenching is a problem that threatens vast tracts of the agricultural land.

f) Older Alluvium

Older alluvium is upland area lying at some distance from the main channel. This unit is out of reach of the flood waters and characteristically possesses a relatively deep water table. Older alluvium is the major geomorphic unit in the area and occupies an area of 359.46 Km^2 (54.82%). This unit is widely marked by intensive cultivation. Within the older alluvium there are localized slightly low lying areas, affected by the water logging, soil salinity or alkalinity or both. The problems of water logging and salinity may be the result of the following factors: rise in the water table, low lying topography, seepage from canal etc. (Sehgal *et al.,* 1973).

g) Meander Scar

A meander scar is formed by the remnants of a meandering water channel. They are characterized by "a crescentic cut in a bluff or valley wall, produced by a meandering stream.Meander scars are portions of the channel that was abandoned when a meander was cutoff (Thornbury, 1990). The abandoned portion of the stream may be occupied with water to creating an oxbow lake.

A meander scar forms when the water empties from the abandoned channel and by the lateral accretion of successive point bars on the inside of the meanders. This deposition creates a ridge and swale topography which is manifested in the form of curvilinear scars on an image.

The meander scars cover an area of 16.62 Km^2 (2.54%) and are mainly identified on the basis of contrasting dark tones in a characteristic winding fashion in association with curvilinear cropping pattern and linearly oriented vegetation (Photo-8).

7.3 Groundwater Potential

Based on the available information and work carried out rainfall is the main source of recharge of groundwater in the study area. One major canal is also found in the outskirts of Agra, which contributes water to the aquifer system. Flooding in the rainy season recharges groundwater in the flood plain. The hydrogeomorphological map of the study area and its environs indicating the potential characteristics of each unit, have been identified and assessed. Morphometric parameters of various sub-basins in the study area are also computed and analyzed in detail to get information quantitatively about the geometry of fluvial system and are correlated with hydrologic information.

The groundwater prospect zones (Fig.7.2) have been classified quantitatively as excellent, very good, good, and moderate to poor on the basis of integrated study of geology, structure, geomorphology, hydrogeology, soil, landuse/landcover and topography, which have direct or indirect bearing on occurrence and movement of groundwater.

7.3.1 Excellent Prospective Zones

Channel bar, meander scar and paleochannel or old river course are the potential reservoir for groundwater and hence useful for groundwater exploration. Soil cover of these units is hydrophilic in nature and has more moisture content as compared to the surrounding areas due to the groundwater flow in these channels, retention of flood water, location contiguous to the river which is mainly responsible for recharge. Gentle slope and vegetation cover are also reason for good groundwater condition since these conditions favors infiltration. Several meander scars near the Pidhaura, Pharaul, Batshwar Temples, Balarpur, Parnai and Laharau are identified adjacent to river channel on the either side. These are the areas of cultivation as ground water is readily available since these are the excellent zones from the ground water point of view. Number of channel bars have also been identified which are seasonally cultivated during the lean flow and inundate during the peak flow.

River channels also come into this category. Fresh water availability is localized along river channels and its proximity. However, the availability of fresh water diminishes away from the channel. Towards upland marginal alluvium where fresh water occurs only in isolated patches.

7.3.2 Very Good Prospective Zones

Point bars fall in this category. This unit is internally drained by river channel and show nearly plain and linear topographic expression. These units are characterized by highly porous and permeable material which facilitates the movement of groundwater; making them the zones of very good groundwater prospect.

These are found all along the Yamuna River channel on the convex side of the meander under the area of investigation.

7.3.3 Good Prospective Zones

Older and younger alluvium are marked as the zones of very good to good groundwater prospect as well as occupies together the maximum area under study. These units are extensively cultivated as the soil here is unconsolidated and fertile. Groundwater in these units under the area of investigation occurs at a depth of ranging from 24.50m to 36.25m in the sand and sandy clay beds. These zones are highly porous and permeable where groundwater occurs mostly under unconfined conditions and move through the interconnected pore spaces, serving as the very good discharge zone. However, older alluvium comprises patches of waterlogged areas and is affected by salinity and alkalinity.

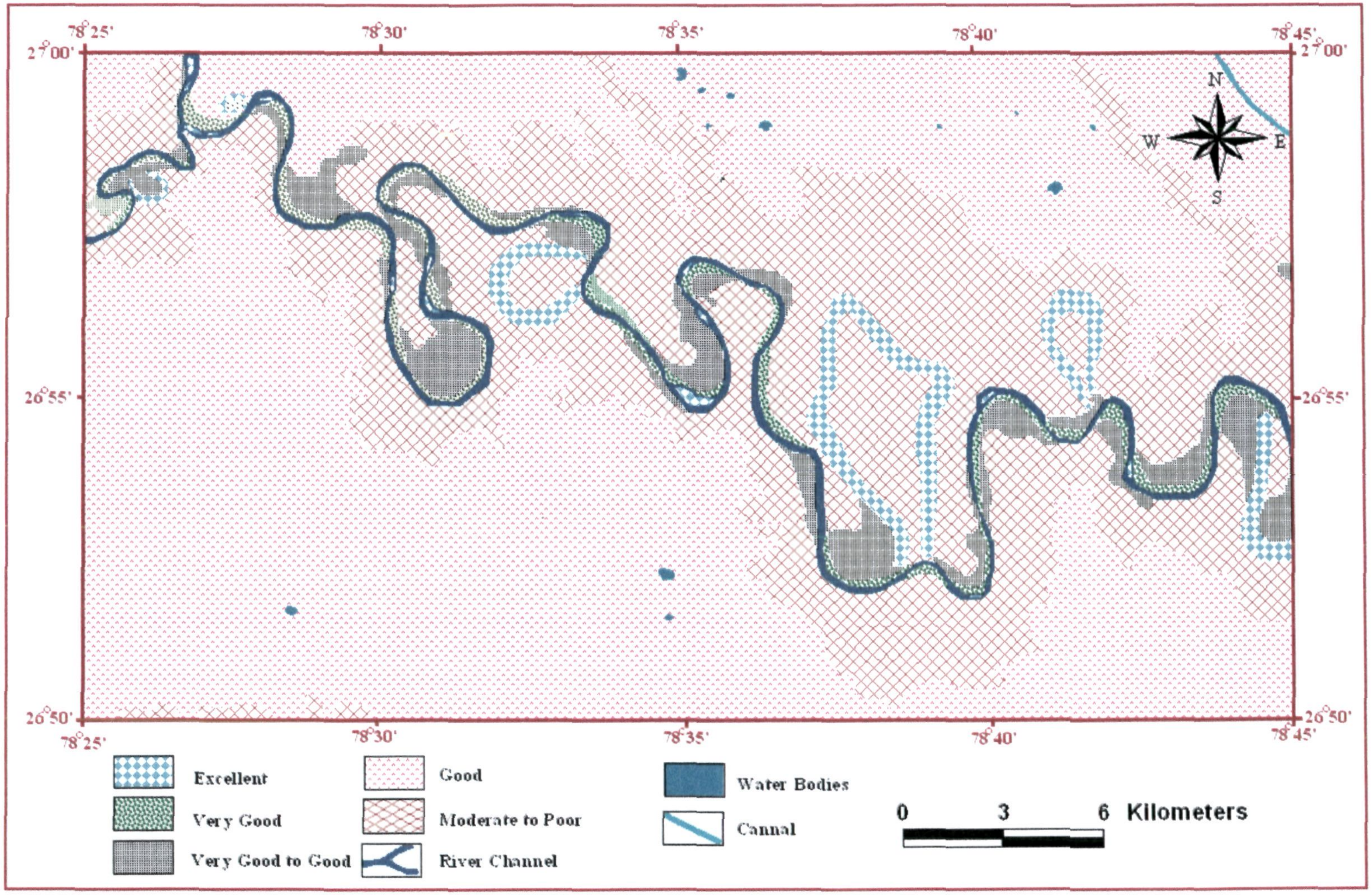

Figure - 7.2 Groundwater prospect map of the study area

Whereas fresh water occurs at relatively shallow depth in younger alluvium, found near the river channel.

7.3.4 Moderate to Poor Prospective Zones

Ravines are very prominent feature found all along the river channels. They are generally formed by intense gulling and certain upliftments of the area, which indicate that the area is tectonically active. They are active areas of soil erosion and represented by low porosity and low permeability hence are the zones of moderate to poor groundwater prospect. The development of ravines along the Yamuna and the Utangan or Gambhir Rivers is not as intense and broad as along Chambal on the south of the Bah Tahsil.

Field Photographs

Photo - 1 Ravinous land in Rudmuli, Bah, Agra

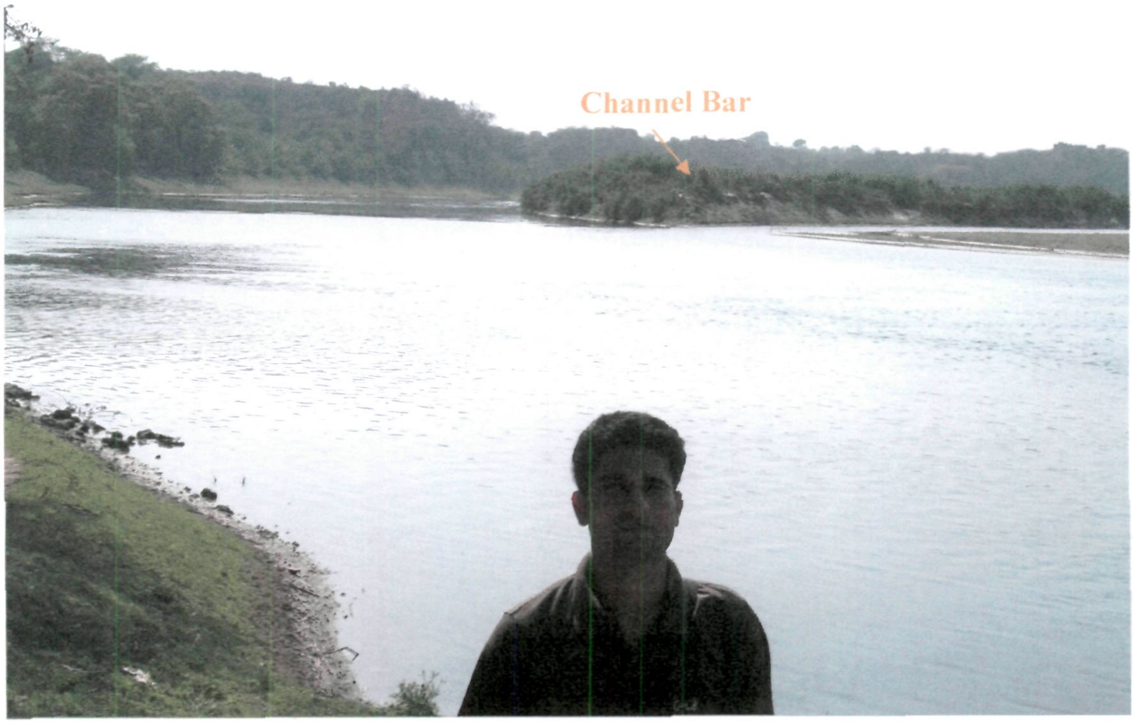

Photo - 2a Channel bar deposit in Yamuna River near Rudmuli, Bah, Agra

Photo - 2b Channel bar deposit in Yamuna River near Rudmuli, Bah, Agra

Photo - 3 Point bar deposit along Yamuna River near Sidhauli, Bah, Agra

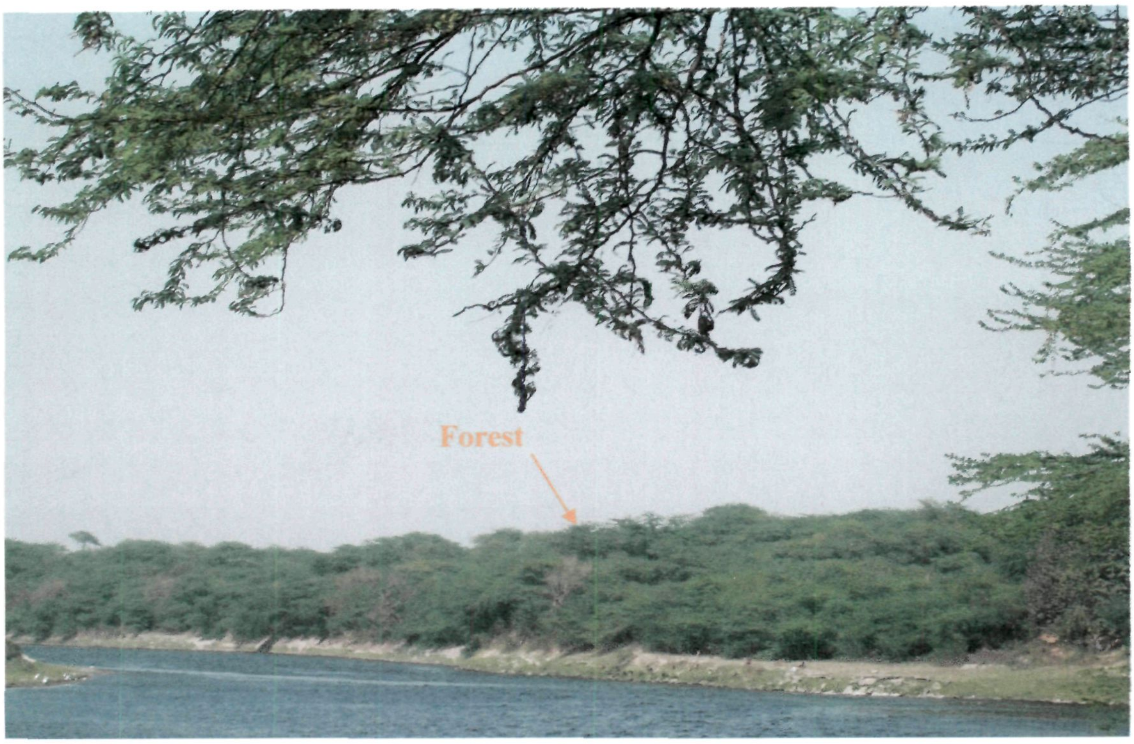

Photo - 4 Bah Reserve Forest (Mainly Babul) Mansurpura, Bah, Agra

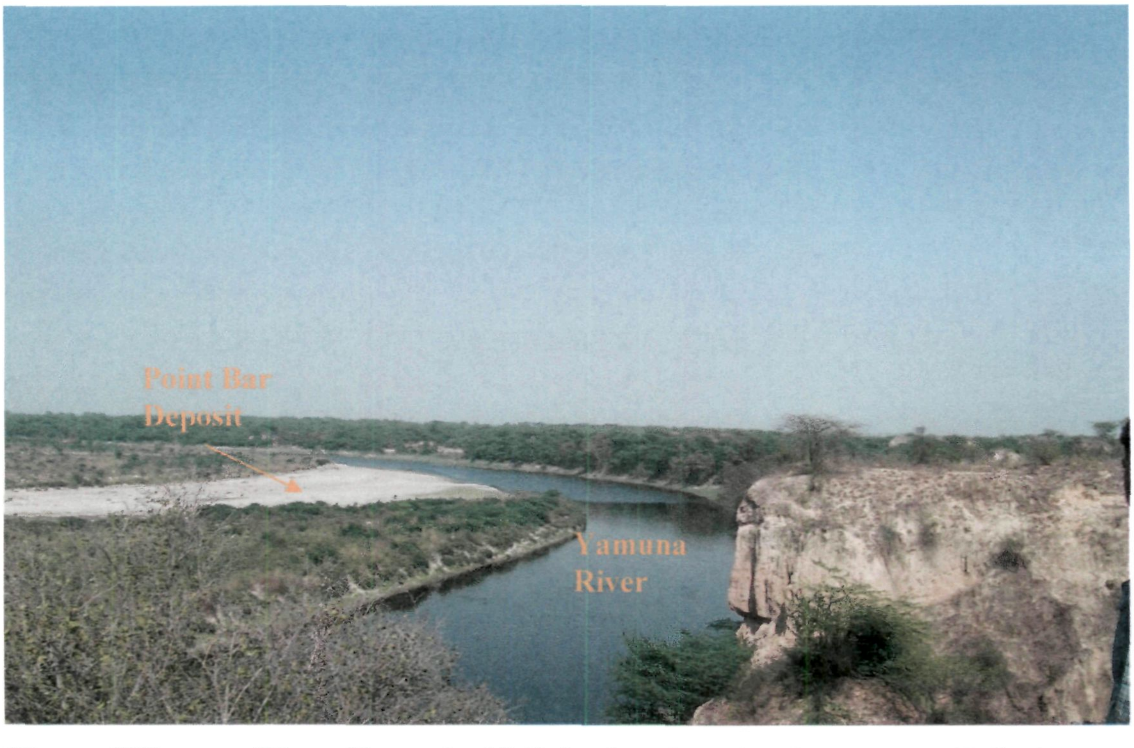

Photo - 5 Yamuna River Channel with Point bar deposit, Mansurpura, Bah, Agra

Photo - 6 Ravinous land Kot, Bah, Agra

Photo - 7 Yamuna River Channel along the Batesar Temples, Batesar, Bah, Agra

Photo - 8 Old River Channel of Yamuna, Batesar, Bah, Agra

Photo - 9 Point bar deposit along Yamuna River Channel, Batesar, Bah, Agra

Photo - 10 Channel bar deposit in Yamuna River near Pidhaura, Bah, Agra

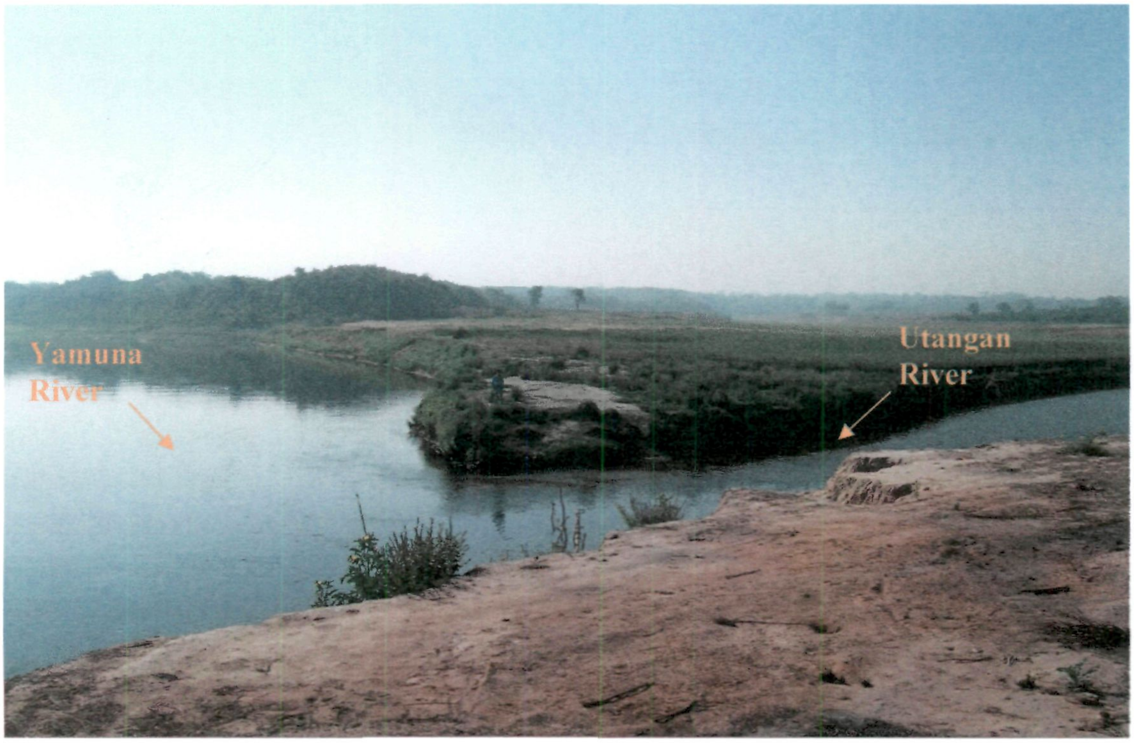

Photo - 11 Sangam of Utangan and Yamuna River, Pidhaura, Bah, Agra

Photo - 12 Utangan River Channel near Pidhaura, Bah, Agra

Photo - 13 Pinahat Reserve Forest (Open Scrub) near Pidhaura, Bah, Agra

Summary & Conclusion

Summary and Conclusion

Agra district is located at the southern fringe of Indo-Gangetic plain at the banks of Yamuna River. It is situated in the extreme southwest corner of the State of Uttar Pradesh and is bounded by Mathura district on the northern side, by Dhaulpur district on the southern side, by Firozabad district on the eastern side and by Bharatpur on the western side.

The large-scale deforestation, mainly due to urbanization, fuel and fodder needs, over exploitation of groundwater, improper water resource management and unscientific management of agriculture practices by the people particularly in Bah Tahsil are some of the major human transformation processes that have been causing reduction in groundwater recharge through increased overland flow and declining rate of infiltration resulting in the lowering of water table upto a considerable depth, which in recent time has become a major concern.

With the ongoing economic and agricultural development taking place in the region, an urgent need is felt to explore the new aquifers in order to meet the increasing demand of water. Therefore the present investigation is aimed to evaluate the groundwater prospective zones through the integrated morphometric, landuse/landcover, hydrogeological, geomorphological and hydrogeomorphological studies in parts Bah Tahsil of Agra district using remote sensing and GIS techniques.

Geologically Bah Tahsil consists of older Alluvium of Middle to Upper Pliestocene age and forms a part of the Indo – Gangetic Plain. The nearest Precambrian outcrop lies about 64 km southwest of Bah. Major part of the area is covered by Gangetic alluvial deposits of the Quaternary period comprising gravel, sand, silt, clay and kankar in various proportions. The thickness of the alluvial cover around the study area ranges from 200 to 250 m approximately.

Clay is commonly found with kankar (calcareous nodules) as revealed from the bore hole data and corresponding litholog. Clay-kankar succession is found interfringed with sand layer of varying size ranging from very fine to medium at a depth of 76 to 81m. Sand is also found to be associated with clay-kankar at a depth of 91m. As the depth increases this clay-kankar layer hardens and is found interlayered with sand. Topmost

16.29m layer is invariably made up of clay and kankar before the first layer of sandy clay. At a depth of 145m sandstone is encountered between two sand layers. Water table is found at a depth of 32m in the sandy clay. Maximum thickness is attained by clay-kankar succession found to be at a depth of 87.5m sandwiched between the sand layers.

The study area is divided into four sub-basins namely Pidhaura, Batesar, Balapur and Pariar. Different morphometric parameters are discussed with respect to the linear, areal and relief aspects. The present study shows that the terrain exhibits dendritic to sub-dendritic drainage pattern suggesting homogenous lithology. The stream order ranges from third to fourth order. Variation in the values of bifurcation ratios among the sub-basins is attributed to the difference in topography and geometric development. The stream frequency values for all sub-basins demonstrate a positive correlation with the drainage density values, suggesting an increase in the stream population with respect to increase in drainage density. Values of drainage density show that the region has highly permeable subsoil, dense vegetation cover and low relief. Drainage texture varies from very coarse to coarse to fine. Shape parameters of the sub-basins viz; *Re*, *Rc* and *Rf* values indicate that the Pidhura and Balarpur sub-basins are more or less elongated, whereas Baetsar and Pariar are more or less circular. Relief aspects and visual interpretation of DEM of the study area indicate gentle to moderate slope, low run off and high infiltrations.

The present study demonstrates that remote sensing techniques and GIS play a vital role for the preparation of updated drainage map and morphometric analysis in a timely and cost-effective manner. Overlaying the shape file of the study area on the satellite imagery available on recently developed ISRO Bhuvan webpage is proved to be efficient technique for calculating the some of the parameters of areal aspects using the measurement tool available on the same webpage.

Furthermore, this study suggests that systematic analysis of morphometric parameters within drainage networks using GIS can provide substantial value in understanding sub-basins; drainage characteristics and hydrogeological behavior of the area. Computation and analysis of morphometric parameters of various sub-basins in the study area has given the quantitative information about the geometry of fluvial system and has been further correlated with hydrologic information.

The water potential of the study area is the main source of surface and groundwater, which experiences very low annual precipitation. The groundwater resource estimates for Agra (alluvial area) categorize the Tahsil Bah under semi-critical category.

In the study area, aquifers belong to the Indo-Gangetic alluvial plain and the groundwater occurs both in unconfined and confined conditions. The water table in the entire Bah Tahsil varies from the depth of 24.30 to 39.00 meter. Moreover, the study reveals that the depth to water in the wells near the rivers is greater than those in the interior possibly due to development of ravines and ranges between 31.55 and 39.00 meter. Generally groundwater movement follows the surface topography which is from west to east.

There is a drastic change in the salinity levels of shallow, intermediate and deep aquifers. The deep aquifers are more saline compared to the shallow and intermediate aquifers. But the salinity level variation in deep aquifers is only marginal and there is a relatively low concentration of constituents, Na^+, K^+, Cl^- and F^-, in deep aquifers as compared to the shallow and intermediate aquifers. Although the concentration of these chemical constituents in a majority of the sites is within the maximum permissible limits, the continuous escalation of these constituents in groundwater can pose a potential health hazard in future.

Hydrogeomorphological units of the marginal and central alluvial plain of the study area, identified on the standard FCC prepared from Landsat ETM+ data by standard visual interpretation techniques, supplemented with the IRS-1D LISS III and high resolution satellite imagery available on Google Earth and Bhuvan webpages with the sufficient ground truth, include River channel, Point bar, Channel bar, Younger/Recent alluvium, Ravinous land, Older alluvium and Meander scars. Older alluvium is the major geomorphic unit of the area and occupies an area of 359.46 Km^2 (54.82%) followed by the ravinous land that covers 219.19 Km^2 (33.43%) and the Younger alluvium 31.90 Km^2 (4.87%). Numbers of meander scars and channel bars have been identified in the area of investigation, occupy an area of 16.62 Km^2 (2.54%) and 11.17 Km^2 (1.7%) respectively. The river channels cover an area of 16.76 Km^2 (2.56%).

The hydrogeomorphological map of the study area and its environs indicating the potential characteristics of each unit, have been identified and assessed for the prospective zones of groundwater. These units have been classified quantitatively as excellent, very good, good, and moderate to poor on the basis of integrated study of geology, structure, geomorphology, hydrogeology, soil, landuse/landcover and topography, which have the direct or indirect bearing on occurrence and the movement of groundwater.

Channel bar, meander scar and river channels are classified as the excellent groundwater prospective zone. Point bars are the zones of very good prospects and good prospective zones include the older and younger alluvium whereas ravinous land has been classified as the zone of moderate to poor groundwater prospect.

Hence the present study shows that remote sensing and GIS can play a vital role in the evaluation of groundwater prospect zones in the study area. The present study reveals that the integration of the Remote Sensing, GIS and DEM with the various geological, geomorphological units, terrain characteristics and drainage network can be used to evaluate the hydrogeomophological zones for the groundwater prospecting in the less studied areas like the study area itself.

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List of Publications

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1) Rao LAK, Rehan S, Ansari ZR, Siddique R **Sadique M** and Islam Z (2009) *Hydrogeomorphological studies for groundwater prospect using IRS-1D, LISS-III image in parts of Agra, district along the Yamuna River, U.P., India.* Jour. of Environmental Research & Development, 3(4):1204-1209.

2) Rao, LAK, Ansari, ZR, Khan S, **Sadique M,** Yusuf A (2010) *Lineament Study of Etmadpur area, Agra District of Uttar Pradesh, India.* Proceedings National workshop on Repair, Renovation and Restoration (RRR) of Water Bodies, CGWB, North Central Region, Ministry of Water Resources, Govt. of India, Bhopal, M.P. pp. 102-107.

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1) Khan A, Kaushar M and **Sadique M** (2008) *Petrofacies and diagenetic evolution of Pachmari Sandstones (Early Triassic) Satpura Gondwana Basin, Central India.* XXV Ann. Conven. of Indian Asociation of sedimentologists and Nat. sem. Sedimentary Basins of India – Their Geological significance and economic propects, from Dec 26-28, 2008.pp-1.

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3) Rao, LAK, Yusuf A., Ansari, ZR, **Sadique M,** (2010) *Morphometric analysis of three sub-basins along Yamuna river in parts of Fatehabad area of Agra district, U.P., India.* Nat. Seminar. Geodynamics and mineral resources of Proterozoic Basins of India, held at Department of Geology & Geoinformatics and Earth Sciences, Yogi Vemana University, Kadapa, from Mar. 4–6, 2010.*Ref.* YVU/DGGE/GAMP2010/47.